Energy and American Society – Thirteen Myths

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CHAPTER 1

INTRODUCTION – THE COMPELLING TANGLE OF ENERGY AND AMERICAN SOCIETY

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1.1. INTRODUCTION

Shortly after the United States had seemingly weathered the energy crisis caused by the 1973 Organization of Petroleum Exporting Countries (OPEC) oil embargo, Senator Gaylord Nelson (1979, p. 2) began a hearing on energy policy by commenting that energy itself is not an end but a means. “We must therefore constantly ask,” he continued, “to what end? What kind of society are we trying to evolve when we make choices about energy technologies?” Such a comment underscores a central theme of this book: namely, the seamless integration of energy and American society.

Senator Nelson’s questions sound even more provocative today, as the country consumes significantly more energy to secure a wider range of services now than it did in 1979. After all, what is more ubiquitous in modern society than energy? It powers our vehicles, lights our workplaces, produces food, enables the manufacturing and distribution of products, cools and warms our homes. Energy is, according to Nobel prize wining economist E.F. Schumacher “not just another commodity, but the precondition of all commodities, a basic factor equal with air, water, and earth” (Kirk, 1977, pp. 1–2). Thus, energy is something used, directly and indirectly, by every person in American culture.

As an example of its omnipresence, consider one of the most widely consumed forms of energy – electricity. In 2002 the U.S. electricity industry possessed over $700 billion of embedded investment, making it the largest investment sector of the American economy (representing 10% of total U.S. capital expenditure). Annual sales of electricity for the same year were approximately $300 billion, close to

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4% of the country's gross domestic product (GDP). To generate this revenue, the electric utility industry consumed almost 40% of the country's energy and nearly 5% of its gross national product (Lovins et al., 2002, pp. 69–71; Masters, 2004, p. 107).

On top of this complexity, the electric utility industry is regulated by 53 federal, state, and city public service commissions and more than 44,000 different state and local codes. During fiscal year 2003, 242 investor owned utilities operated about 75% of the country's total electrical capacity in addition to more than 3,187 private utilities, 900 cooperatives, 2,012 public utilities, 400 power marketers, 2,168 non-utility generating entities, and nine federal utilities. These organizations distributed their electricity through roughly 500,000 miles of high voltage transmission lines and an ever greater number of distribution lines (Palast et al., 2003).

When grappling with these complex issues, the bulk of studies concerning energy and American society tend to focus on either assessing individual technologies or forecasting energy futures.

Regarding the first approach, technology assessment, most of the recent policy briefs and books that address energy in America attack the problem within technologically and disciplinarily narrow boundaries. The Edison Electric Institute (EEI) and Electric Power Research Institute (EPRI) tend to center purely on the economics of electricity supply and demand, while reports from groups like the Pew Center on Global Climate Change and the Natural Resources Defense Council emphasize the environmental dimensions of energy consumption. The National Academies of Science and Union of Concerned Scientists have produced insightful analysis of the security and infrastructure challenges facing the energy sector, while groups like the Alliance to Save Energy and the American Council for an Energy Efficient Economy remain principally concerned with conservation and energy efficiency. Those that analyze particular types of energy supply – such as the Nuclear Energy Institute, American Wind Energy Association, the American Solar Energy Society, or the Combined Heat and Power Association – often confine their analyses to a limited range of technologies, rarely exploring how such technologies operate in society as a whole.

This "stove piping" approach also carries over into the design and pursuit of the nation's energy research and development (R&D) – in all layers of government, academe, and industry. Integrative concepts that combine systems and cut across technologies, disciplines, and sectors of the economy are difficult to pursue. Developing sweeping novel concepts is an inter-disciplinary, complex undertaking that requires new partnerships and alliances and a broad understanding of technologies and markets. At the same time, the combination of concepts into more efficiently functioning systems could have large and positive implications for energy futures.

For example, in a recent review of the U.S. climate change R&D portfolio, the lack of focus on integrated technologies was seen as a critical gap (Brown et al., 2006). Several illustrations of merged suites of technologies that have received limited attention include:

- **Plug-in hybrid electric vehicles (HEVs)**: Integration of plug-in HEVs with the electric grid for both recharging and discharging power and to support utility peak-shaving could dramatically reduce energy consumption and greenhouse gas emissions from vehicles if recharging is done principally with low-carbon forms of electricity such as nuclear or renewable resources.
- **Systems engineered urban planning and design**: Land use can be designed to reduce travel requirements and foster the co-location of activities with common needs for energy, water, and other resources, resulting in greatly diminished requirements for transportation fuels; greenhouse gas emissions could be further reduced through the co-location of energy sources and carbon sinks.
- **Systems approach to integrated waste management**: The energy used in waste management and the utilization of methane from landfill gases can be optimized through systems that involve product tagging and sorting to maximize energy recovery from waste, reuse and recycling as well as distributed waste processing (e.g., in homes, businesses, and industry) for conversion to power and fuels.
- **Water–energy nexus**: Water and energy are inextricably bound together in today's society, and any future technologies that address one will likely impact the other. Ultimately, society needs more efficient use of energy to support water distribution and treatment, and more efficient use of water to support energy supply; these cross-linkages have gone largely unexamined.

Thus, the need for new and creative approaches assessing the intersection of energy systems and society at large are almost as urgently needed as they are unlikely to occur in contemporary discussions about energy policy in the United States.

The second popular approach taken by analysts concerned with energy and society is to perform technological forecasts. Reports from the U.S. Energy Information Administration (EIA), Environmental Protection Agency (EPA), and International Energy Agency (IEA) typically focus on estimating generation capacities, projecting fuel costs, and predicting the environmental impacts of particular energy technologies. For example, the paragon of excellence among these types of reports, the EIA's *Annual Energy Outlook* (EIA, 2005b), predicts the current and future technical potential for energy technologies, but does not anticipate expected policy changes or provide policy recommendations. As Amory Lovins (2005), director of the Rocky Mountain Institute, recently told senators, "the *Annual Energy Outlook* is not fate; it is not a mandate that one must fulfill; and it absolutely does not illuminate the true range of national choice." R. Neal Elliott (2005, p. 84) adds that "the EIA needs updated modeling capability to reflect adequately [the new] market realities facing the American electric utility sector." In other words, energy forecasts often assume the existing configuration of the industry, and thus restricts their consideration to a very narrow range of alternatives.

For instance, such forecasting tools typically focus on averages and do not explore the underlying compositions that constitute such data, thereby overlooking the wide variations of submarkets and trends that can be hidden through the process of compiling statistics. Historian Theodore Porter (1995) notes that the process of such quantification has many flaws, including (but not limited to) the choice of samples, preservation of samples, control of reagents, methods of measurement, custody of samples, methods of recording data, training personnel, controlling bias, and the formation of categories. Sociologist Nikolas Rose (1991) adds that political judgments are implicit in the choice of what to measure, how to measure it, how often to measure it, and how to interpret the results. For example, in characterizing energy resources, the EIA uses categories of fuels such as coal, oil, natural gas, nuclear, and renewable resources. The omission of energy efficiency from this mix reinforces the perception that a megawatt saved (i.e., a "negawatt") is not as valuable as a megawatt generated. Quantification is no less arbitrary and subjective, in the end, than any other human activity. Yet, as a culture, we choose to lend "numbers" (and the reports that they constitute) immense power.

Moreover, such forecasters typically fail to use "statistical backcasting" to analyze the validity of their models based on historical patterns and trends. A report from the Lawrence Berkeley National Laboratory recently conceded that:

> One of the most striking things about forecasters is their lack of historical perspective. They rarely do retrospectives, even though looking back at past work can both illuminate the reasons for its success or failure, and improve the methodologies of current and future forecasts.
>
> (Koomey et al., 2003, p. 2)

The exclusion of historical perspective tends to make energy forecasts extremely unreliable. Historian Vaclav Smil (2004, p. 121) argues that "for more than 100 years long-term forecasts of energy affairs – no matter if they were concerned with specific inventions and subsequent commercial diffusion of new conversion techniques or if they tried to chart broad sectoral, national, or global consumption trends – have, save for a few proverbial exceptions confirming the rule, a manifest record of failure." Such problems inherent to energy forecasting could help explain why between 1945 and 1960 there were more than 544 incorrect forecasts of a peak in American oil production, but only one – made by M. King Hubbert in 1954 – predicting, correctly, around 1971 (Yergin, 1991; Adelman, 1995; Deffeyes, 2001).

To be fair, forecasting constitutes a notoriously chancy endeavor. Even in the field of meteorology, detailed predictions are not practical but for a few days ahead. Political and social forecasting, of course, is even more difficult. In Oliver Cromwell's time, many educated Englishmen believed that God would bring the order of things to an end in the 1650s, and thus looked in the *Book of Revelations* for allusions to a 17th century Armageddon. Famed economist Thomas Malthus prophesized in 1798 that human population growth would create "periodical misery" that will "forever continue to exist" unless humanity learned to drastically lower its birthrate. In his assessment of forecasts, philosopher Stephen Toulmin (1992) notes that historical agnosticism and short-sighted thinking have plagued educated people for hundreds of years. All of these difficulties led Alan Kay (2006, p. ii), pioneer of the personal computer, to conclude that "It is easier to invent the future than to predict it."

Nonetheless, each of these two approaches can be very useful – assessments of individual technologies help track their diffusion into society, and forecasts offer a dynamic tool for projecting the consequences of a society's energy choices.

Veritably, almost every chapter in this book – including this one – partly relies on some form of technology assessment and energy forecasting. Yet we believe that analysts must also recognize that neither approach can provide, on its own, an interdisciplinary or holistic analysis of energy technologies that takes into account how cultural attitudes and social interests intersect with patterns of energy production and consumption. Thus, assessments and forecasts must always be contextualized and enhanced by an exploration of social, economic, political, and cultural factors.

Indeed, energy issues in contemporary society are so prolific that to write about them could really be to write about anything (from the managerial practices of small electric utilities to the way that natural gas has subtly impacted gender roles and the work that women undertake in their home). We have chosen instead, however, to write about "myths." Why, the good reader may ask?

1.2. THE IMPORTANCE OF MYTH IN CONTEMPORARY ENERGY POLICY

The answer lies in the ability for myths to refer not to the absolute truth of a given fact, statement, or belief, but to instead represent what people perceive to be true. Anthropologists, historians, psychologists, and philosophers tend to define myths as "stories, drawn from history, that have acquired through usage over many generations a symbolizing function central to the culture of the society that produces them" (Slotkin, 1987, p. 70). At their best, myths "are never themselves factual: they are products of the imagination, complex mental constructs" (Kuklick, 1972, p. 436). Exploring the mythic level of energy and American society, then, gets less into debates over absolute "truth" and more into an investigation of attitudes, values, and underlying assumptions.

Traditionally, the study of myth was intended to distinguish between fact and fiction. In its historical and common usage, the words myth and fact are used to denote contradictories. A story, we are told, is likely to be true or false. If true, it is fact; if false, myth. Popular examples of what many scholars classify as myths range from the Greek narratives of Oedipus and the gods to campfire stories about Paul Bunyan and Babe the Big Blue Ox and alligators in the sewer. Such conceptions, however, create a binary opposition between myth/fantasy and reason/science (Bidney, 1950; Bidney, 1955; Hyman, 1955; Munz, 1956; Watts, 1971; Segal, 1980; Campbell, 1981; Foster, 1984; Doty, 1986). This dichotomous conception of myth is then often used to distinguish between primordial/primitive cultures and scientific/advanced ones. The distinction is well encapsulated in Rubin Gotesky's (1952, p. 523) statement that "the more scientific a society the more capable it is of distinguishing between myths and non-myths. Consequently, it follows the more scientific a society, the fewer myths it holds." Jeffrey Schrank (1973, p. 22) adds that "myths are usually disposed of in the category of things people did long ago before they knew any better."

For the purposes of this book, however, we advance a slightly different interpretation. Social theorist Claude Levi-Strauss (1995) argues that one can find myths wherever one finds language and culture. Thus, he argues, all cultures, whether "primitive" or "advanced," employ myths to cope with the tensions of life, to explain natural events, and to interpret their history. The fundamental importance, Levi-Strauss emphasizes, is not whether myths exist – they do, regardless of how much a culture has progressed – but what such myths reveal about society. The study of myth then becomes not just the study of folklore versus fact, but instead a useful technique for identifying popular consciousness and engrained ways of thinking (Kuklick, 1972, p. 61). In this way, historian Read Bain (1947, p. 1) has stated that "to a considerable degree, the history of humanity is the history of myths."

Viewing myths in this manner has manifold benefits, two general and two specific. First and generally, *it reveals important dimensions about our culture*. Law professor Susan H. Williams (1986) comments that myths can be interpreted as a kind of shorthand, or condensed codification, of accumulated cultural understanding. Even if such myths are patently false, Williams holds that "myth, with all of its incongruity and contingency, is the stuff of which culture is made" (p. 154). David Bidney (1955) emphasizes that, since myths are about constructing a particular social reality, they create a symbolic representation of what a given group of people wish to be true. And Philip Wheelwright (1995, p. 473) has suggested that "all knowledge involves, at the instant of its reception, a synthesizing activity of the mind – into the key of myth."

Second, *the process of identifying and interpreting myths enables the process of demystification*. As any good storyteller knows, myths, once espoused, often take on a life of their own. They become constantly reproduced and perniciously accepted. Their great appeal lies in their ability to reduce the growing complexity of the world into a simple, knowable, and memorable idea. In time, though not always based on fact, such ideas can come to constitute reality, sometimes appearing as true as a "fact of nature." Thus myths serve to restrain thought and behavior, and can become powerful tools for sustaining a particular vision of the world (Bain, 1947; Nimmo and Combs, 1980; Slotkin, 1987). The process of demystification – revealing the origins and assumptions behind a given myth – can then become an important process for reasserting individual autonomy.

Third and specifically, *an emphasis on myths reminds us that energy technologies are both social and technical*. Most analysts, in contrast, tend to discuss the innovation and diffusion of energy systems in purely technical terms. For example, many engineers and physical scientists propose that technology progresses in a rational, ordered, and predictable manner. They see "science and technology as an assembly line," which begins with basic scientific research, follows with development and marketing of a given technology, and ends with the product being purchased by consumers (Wise, 1985; Elliott, 1988). In contrast, we believe that energy technologies co-evolve with society so that social attitudes of manufacturers and users influence the course of technical change as much as the hardware. Historian Thomas J. Misa (2003, p. 3) elaborates that "technologies interact deeply with society and culture, but the interactions involve mutual influence, substantial uncertainty, and historical ambiguity." And historian David E. Nye (1999, pp. 5–6) argues that:

> Machines are not like meteors that come unbidden from the outside and have impacts. Rather, each is an extension of human lives: someone makes its components, someone markets it, some oppose it, many use it, and all interpret it. . .No technological system is an implacable force moving through history; each is a part of a social process that varies from one time period to another and from one culture to another.

In other words, we believe that energy technologies and society are intricately and faultlessly connected, and that the question of whether a technology will succeed or fail depends equally on technical feasibility and social acceptance.

Fourth, *investigating energy myths pushes otherwise invisible elements of our culture to the foreground*. Energy systems have become so entrenched in American society that people rarely think critically or constructively about them, if at all. Historian James C. Williams (2001) argues that people know that technology and technological systems are the tools with which they interact in their everyday lives. But once technological landscapes are in place, people fold them so completely into their psyches that those very landscapes become almost invisible. For instance, historian David Nye (1999) argues that such technological environments appear natural because they have been there since the beginning of an individual's historical consciousness. According to Nye (pp. 6–7):

> The energy systems a society adopts create the structures that underlie personal expectations and assumptions about what is normal and possible. . .Each person lives within an envelope of such natural assumptions about how fast and far one can go in a day, about how much work one can do, about what tools are available, about how that work fits into the community, and so forth. These assumptions together form the habitual perception of a sustaining environment that is taken for granted as always there.

A child born into a world with automobiles and airplanes, Nye notes, takes them for granted and learns to see the world naturally at hundreds of kilometers an hour. Similarly, it appears that most people have become enfolded into the vast technological network of the electric utility system so that they don't even realize such a system exists. Thus, when surveyed about possible ways to expand the supply of electric power, consumers have suggested that homes simply be provided with more outlets – overlooking the fact that expanded "plug loads" usually require power plant expansions, more transmission lines and towers, and the addition of new transformers and substations.

Consequently, in today's culture most people conceive of technology only as the latest high tech items, such as new and rapidly emerging technologies and systems. Inventions of far larger historical significance – pottery, paper, electricity – no longer "count" as technology. Sociologist Paul N. Edwards (2003, pp. 185–186) remarks that:

> The most salient characteristic of technology in the modern (industrial and postindustrial) world is the degree to which most technology is not salient for most people, most of the time. . .The fact is that mature technological systems – cars, roads, municipal water supplies, sewers, telephones, railroads, weather forecasting, buildings, even computers in the majority of their uses – reside in a naturalized background, as ordinary and unremarkable to us as trees, daylight, and dirt. Our civilizations fundamentally depend on them, yet we notice them mainly when they fail, which they rarely do.

To explore the myths regarding energy systems, then, is almost like investigating the invisibility of an already seemingly invisible set of technologies. And because they coincide with what people already believe to be true, myths about energy are often tacitly accepted without critical examination. Consequently, revealing myths relating to energy supply, demand, and consumption can be an important tool for revealing perpetually eclipsed dimensions of American culture and society. Focusing on such aspects can also be useful for indicating points of tension and contradiction, forcing those concerned with energy to become more comprehensive and reflexive in the way they conceive of, talk about and – most important – make decisions concerning energy.

1.3. PUBLIC KNOWLEDGE AND THE CHALLENGES FACING THE CONTEMPORARY ENERGY SECTOR

Ironically and perhaps incongruously, there is a growing belief among sociologists, historians, and political scientists that because our modern society is becoming more knowledge intensive, people are naturally becoming better informed about how energy is generated, transported, and used, and about how it is regulated and incentivized through public policy. Arthur L. Costa (2006, p. 62) recently noted that we are entering an era in which:

> Knowledge doubles in less than 5 years, and the projection is that by the year 2020 it will double every 73 days…Our world has shifted away from an industrial model of society to a learning society.

Reforms in education, a growing public interest in contemporary affairs, and improvements in telecommunications and information processing (such as more advanced computers and growing access to the internet) are all seen as driving this new knowledge-based economy. Matt Leighninger (2004, p. 38) thus concludes that democratic organizers are finally able to "foster that kind of well-rounded, active citizenship" that they have so yearned for.

These changes, the thinking goes, have assuredly begun to produce a more energy-aware, environmentally-conscious, and knowledgeable American society. For instance, Susan Charnley and Bruce Engelbert argued in 2005 (p. 165) that:

> Recent decades have seen a dramatic increase in public participation in environmental decision-making conducted by government agencies. This increase has been driven both by citizens who demand a greater role in shaping the decisions that affect their well-being, and by agencies that recognize the benefits of involving citizens in their decision-making processes.

David Morris (2006, A3) remarked that "high oil prices, energy security concerns, and a growing awareness of climate change have put the prospect of a carbohydrate economy back on the public agenda." Michael J. Brandemuehl (2005, p. E4) agrees and states that "awareness of energy challenges comes in waves, and one seems to be building today." A survey on international green businesses conducted by *The Guardian* suggested that "the time may never have seemed better to start a social enterprise – public awareness of fair trade is growing, the green guilt that afflicts us all is just waiting to be assuaged, and more money is being directed into ethical investments" (Tickle, 2005, p. 3). Similarly, a 2005 *Energy Policy* article noted that the lengthy public campaigns and education aimed at urging careful energy use, enforcement of efficiency related regulations, and improved tariff structures for various forms of energy have made between 10 and 30% of Americans more aware of their energy decisions (Jaber et al., 2005, p. 1329). And Paul DeCotis of the New York State Energy Research and Development Authority even went so far as to say that the Energy Policy Act of 2005 "successfully put energy at the forefront in public dialogue, and coupled with higher energy prices, unstable supplies, and catastrophic events like Hurricanes Katrina and Rita, it has heightened the awareness of energy issues in the minds of consumers, policymakers, and politicians" (Sovacool, 2006, p. 287).

As a direct challenge to these claims, we believe that the vast majority of the American public – including some policymakers and industry leaders as well – remain uninformed about many dimensions of American energy policy. Correspondingly, understanding energy myths and designing strategies to correct them to better reflect a more complicated reality requires a comprehensive knowledge of how energy is produced, distributed, and used. The urgency of this myth adjustment process is underscored by the severity of the energy challenges facing the nation and the many worsening energy trends and patterns.

The American energy sector has been massively transformed during the last three decades. Viewed previously as a stable, secure, and heavily regulated consortium of coal, natural gas, oil, and electric utility industries, the system has shed elements of government oversight and now appears to be quite susceptible to natural disasters, terrorist attacks, and other disruptions including market manipulation. Despite the conventional wisdom learned by policymakers during the energy crises of the 1970s, the modern energy sector continues to face many of the same problems that existed 30 years ago. These problems have been exacerbated by the steady and rapid increase in U.S. energy consumption, which grew by nearly 50% between 1970 and 2004 (EIA, 2005a, Table 1.5, p. 13).

While considerable effort has been dedicated to the development of composite indicators of U.S. transportation productivity, environmental quality, and educational effectiveness, there are no standard composite metrics to evaluate the condition of the U.S. energy system. To fill this gap, we have developed an "energy sustainability indicator" (ESI) of the U.S. energy system comprised of twelve indicators (Figure 1.1). The indicators cover four dimensions: oil security, electricity reliability, energy efficiency, and environmental quality. Comparing these 12 indicators in 1970 with 2004, nine have trended in an unfavorable direction, two have moved in a favorable direction, and one has remained essentially unchanged. Assuming each indicator is of equal importance, a summary ESI of – 7 results for the comparison of 1970 with 2004.

The four indicators of *oil security* suggest worsening or at best stagnant conditions. The rapid growth of U.S. oil consumption – combined with shrinking domestic oil production – has resulted in increased dependence on imported oil, which now accounts for 58% of total U.S. oil consumption – up from 22 % in 1970 (EIA, 2005a, Table 5.7). Recent trends in world oil markets, including the emergence of China and India as major contributors to global demand, continuing instability in

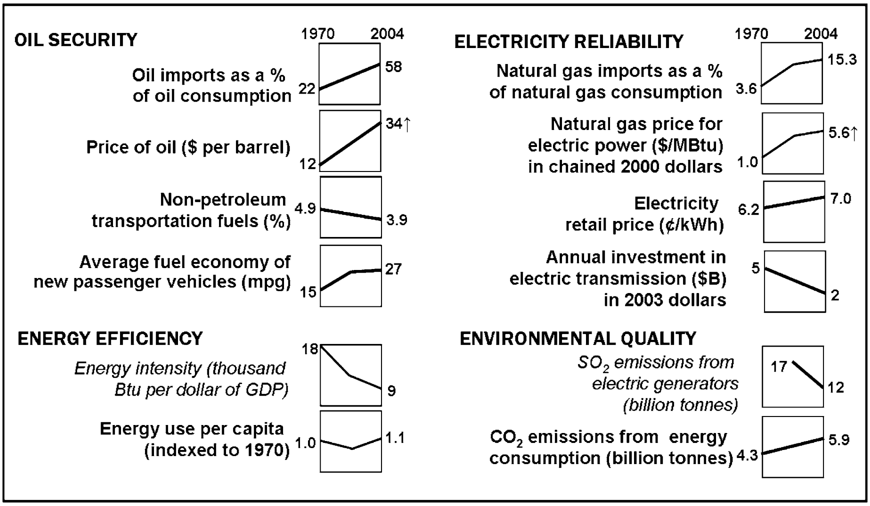

Figure 1.1. An energy sustainability index for the U.S. Energy System (Financial metrics are in $2004 unless otherwise indicated. The three metrics shown in italics represent favorable trends; all other metrics suggest deteriorating conditions.)

the Middle East, and refinery outages from Gulf Coast hurricanes have caused the price of oil to spike in recent years, rising from its historic average of $12/barrel in 1990 to $34/barrel in 2004 and exceeding $70/barrel (in real terms) during much of 2005 and 2006 (EIA, 2005a, p. 167). Fuel diversity is an important long-term strategy for coping with oil dependence and price volatility, but it has not improved: non-petroleum fuels actually represent a smaller fraction of the energy consumed by the U.S. transportation sector in 2004 (at 3.9%) than in 1970 (when it was 4.9%) (EIA, 2005a, Table 2.1e, p. 42). Finally, the situation is exacerbated by the fact that the fuel economy of cars has been essentially unchanged for more than two decades.

Electricity reliability is also threatened. Volatility in natural gas markets, sustained price increases, and increasing natural gas imports are prompting concerns about this environmentally friendly fuel, which has become a preferred choice for new power plants over the past decade. Natural gas imports have grown from 3.6% of U.S. natural gas consumption in 1970 to 15.3% in 2004, placing U.S. demand for natural gas increasingly under the control of unstable world markets (EIA, 2005a, Table 6.1, p. 185). Natural gas prices have been rising as well, especially for electric power production, with average prices of $5.6/MBtu in 2004 compared with historic prices of $1.0/MBtu.

As the result of increasing demand for electricity and rising fuel prices, the cost of electricity is rising. The average retail price of electricity for all customers rose in real terms from 6.2 cents per kWh in 1970 to 7.2 cents per kWh in 2004 (EIA, 2005a, p. 259). Proportionately, 22 utilities increased rates for their customers in 2005, and more than 40 utilities are expected to do so by the start of 2007. The end of June revealed Delmarva Power business customers in Delaware experiencing real rate increases as high as 118%. Baltimore Gas and Electric Residential have announced real rate increases of 72%. Other customers in New Jersey will likely see rate increases of 28%; those in Florida 29%; those in Wisconsin 14.4% (Ackerman, 2006; Lenssen et al., 2006).

Compounding these price and fuel reliability issues, the U.S. transmission system continues to experience stress from the combination of increasing power flows and declining grid investments. United States expenditures in transmission infrastructure peaked at almost $10 billion in 1970, but it has declined to less than half that amount annually over the last two decades (EPRI, 2003, pp. 2–4; EEI, 2005, pp. 1–3). Patrick Lanning, the president of a mid-size utility serving 83,000 customers in Oregon, recently told investors that his electric grid was so underfunded that 85% of his transmission and distribution poles were at least 30 years old. Lanning cautioned that "wires, circuit breakers, substations and other equipment are nearing or have reached the end of their useful life and are in need of replacement or upgrading. If we don't start taking care of these needs now, reliability will slip below acceptable levels" (Ackerman, 2006, p. 14). The EEI also notes that transmission congestion is dramatically increasing. Requests from system operators for transmission loading relief in the eastern part of the U.S., for example, rose from around 50 in July 1998 to 180 in July 2002 and more than 275 in July 2004 (Ackerman, 2006).

The two indicators of *energy efficiency* are inconsistent in their directional trends. On the positive side, the demand for energy has not been expanding as rapidly as the economy has been growing. In 1970 the United States consumed 18.0 thousand Btu per dollar of GDP (in real terms), while by 2004 this measure of energy intensity had dropped to 9.2 (EIA, 2005a, Table 1.5, p. 13). On the negative side, however, energy use per capita is increasing. Using a metric indexed to 1.0 in 1970, energy use per capita is now approaching 1.1. The EEI, for instance, estimated that 1.1 million new residential and 180,000 new commercial customers were added to the national power grid in 2005, and that the kilowatt hours (kWh) consumed per customer grew 5.95% between 2004 and 2005 (Ackerman, 2006).

Similarly, the two indicators of *environmental quality* are mixed. Cars, trucks, and fossil fueled power plants discharge and distribute sulfur dioxide (and other air pollutants) and carbon dioxide (and other greenhouse gas emissions); they therefore threaten human and ecosystem health. On the one hand, between 1989 and 2003, SO_2 emissions from electricity generation and combined heat and power systems decreased dramatically: from 17.1 million tons in 1989 to 11.7 million tons in 2003 (EIA, 2005a, Table 12.7a, p. 351). On the other hand, total U.S. emissions of carbon dioxide from energy consumption have increased significantly: from 4.3 billion metric tons in 1970 to 5.9 billion in 2004 (EIA, 2005a, Table 12.2, p. 341; CDIAC, 2006).

Turning these trends around will require an understanding of the many technical and non-technical barriers that thwart progress. Key myths that embody many of these barriers are described in the following chapters and are summarized below.

1.4. EXPOSING THE THIRTEEN ENERGY MYTHS

In its broadest sense, this book is an attempt to educate and inform the public about energy policy. It takes on a central quandary in the studies of energy and environmental policy: what myths continue to exist in American culture concerning energy, the environment, and society? We extend that question to ask: how can these myths be reexamined and debunked, so that citizens, policymakers, entrepreneurs, students and scholars can come to create a more sustainable energy future? And, finally, how can the public make sense of recent crises and situations in the American energy sector?

The exploration of these questions is built around 13 central myths that we believe persist and persevere in American society. The first two of these myths address broad issues of energy and American society that crosscut all of the indicators in the energy sustainable index.

The first myth is that *today's energy crisis is "hype."* In this chapter, Marilyn Brown documents the many reasons people do not believe an energy crisis exists or is imminent. These include the beliefs that the nation's energy problems are (1) fabricated – e.g., through marketplace manipulation and price gauging; (2) a cover-up – e.g., for pro-industry or anti-environmental policies; or (3) exaggerated – e.g., because resources and technology solutions are actually sufficient. In reality, the nation's energy system is as challenged today as it was 30 years ago, and options do not exist to ensure a sustainable energy future. Five dimensions of this crisis are documented: persistent oil vulnerability, power supply problems, the fragile energy infrastructure, the untapped potential for energy efficiency, and the energy-environment nexus. Passage of the Energy Policy Act (EPAct) of 2005 with its 1,724 pages of energy legislation may give the impression of a nation prepared to meet its future energy needs. However, alternative policy recommendations such as those of the National Commission on Energy Policy and the Energy Coalition illustrate the more expansive government actions required to address the nation's energy challenges. The myth that the energy crisis is "hype" must be corrected so that sizeable resources can be mobilized to meet the nation's real and significant energy challenges.

The second myth is that *the public remains well informed about energy and the environment.* In this chapter, Rosalyn McKeown notes that despite two oil crises, the rise of the environmental movement, and the sheer quantity of information available to the public, most people in the United States do not understand the complexities of how energy is provided, delivered, and used.

The results of a 2001 survey of U.S. households show that the American public has a low energy IQ, while at the same time people overestimate their level of knowledge. In addition, Americans are only vaguely aware that their energy consumption has huge negative effects on the environment. Given the importance of an informed public to successful community-based decision-making and to public participation at all levels of government, more free-choice learning opportunities are needed. These should span all five goals of environmental education: raising awareness, building knowledge, developing skills, identifying values, and having the opportunity to participate in problem resolution. To deal with the mounting national energy challenges, the myth that the public is well informed needs to be converted into a reality.

Three of the 13 myths pertain to the issue of *oil security*. They address competing views that have spurred great debate, including opinions about the availability of land for food versus land for fuels, the hype about hydrogen versus the real potential of plug-in hybrid electric vehicles, and the ability of prices and market forces to deliver solutions versus the need for public intervention.

The third myth is that *high land requirements and an unfavorable energy balance preclude biomass ethanol from playing a large role in providing energy services*. The chapter by Lee Lynd, Mark Laser, John McBride, Kara Podkaminer, and John Hannon deals with one of the more pernicious myths circulating in the bio-fuel debate, which suggests that there simply isn't enough land to support crops for both energy and agriculture. Also addressed is the persistent myth that the amount of fossil fuel energy required to produce ethanol from lignocellulose is greater than the energy contained in the fuel obtained. The latter is discredited conclusively by a brief but definitive analysis showing a decidedly positive fossil fuel displacement ratio for well designed processes over a broad range of assumptions. Key factors underlying the potential supply of biomass feedstocks are addressed, with consideration also given to why estimates for the future contribution of biomass energy are so divergent. These factors include both technological innovations – especially increases in process fuel yield and per-acre biomass yield for both energy and food crops – and behavioral changes such as vehicular and dietary choices. The authors suggest that new practices incorporating biofuel feedstock production into currently-managed lands, involving both technological and behavioral changes, are often neglected when evaluating future biomass feedstock availability and could make a large contribution while easing land demand. Given foreseeable technological innovations in per-acre fuel production, half of current gasoline demand could be met via cellulosic biofuels produced from 50 million acres, an amount of land likely to be available. If technical innovations are coupled with behavioral changes favorable to increased biomass availability, the authors conclude that it becomes realistic to contemplate biomass providing all U.S. mobility requirements.

The fourth myth is that *the hydrogen economy is a panacea to the nation's energy problems*. In refuting this myth, Joe Romm concludes that efficiency is the most cost-effective near-term strategy for reducing emissions and petroleum use. Ultimately, we will need to replace gasoline with a zero-carbon fuel to achieve deep reductions in greenhouse gas emissions. All alternative fuel vehicle (AFV) pathways require technology advances and strong government action to succeed. On the technology side, hydrogen vehicles are the most challenging alternative fuel because they require multiple scientific breakthroughs to be practical and because of the enormous effort needed to change the existing U.S. gasoline infrastructure. The most promising AFV pathway is a hybrid that can be connected to the electric grid. These so-called plug-in hybrids or e-hybrids will likely travel three to four times as far on a kilowatt-hour of electricity as fuel cell vehicles. Ideally these advanced hybrids would also be fuel-flexible, capable of running on a blend of biofuels and gasoline. Such a car could travel hundreds of miles on one gallon of gasoline (or five gallons of cellulosic ethanol) and have under one-tenth the greenhouse gas emissions of current hybrids. The myth that the hydrogen economy is a panacea supports the diversion of scarce public resources away from more promising and more realistic alternatives.

The fifth myth is that *price signals are insufficient to induce efficient energy investments*. Jerry Taylor and Peter Van Doren illustrate this myth with a case study of gasoline prices. Economists believe that government intervention in markets, including energy markets, improves economic efficiency if and only if market failures exist and the policy intervention enacted actually corrects the market failure. They enumerate some of the characteristics of energy markets that give rise to charges of energy market failure. Examples are that the preferences of future generations are not reflected in energy prices, that supply and demand do not change much in response to price changes in the short run, and that energy prices do not reflect the substantial health, environmental, and national security costs of fossil fuel use. Jerry Taylor and Peter Van Doren examine those arguments in detail and find them to be generally unpersuasive. In most cases, they argue that energy prices are reasonable reflections of market conditions. Those distortions that do exist are often the result of existing policy. The best remedy for those problems is elimination of existing government policies rather than adoption of new countervailing interventions.

Three chapters tackle myths surrounding *electricity reliability*. They cover the topic of non-technical barriers to technology innovation, the potential for renewable power options, and the role of industry restructuring and distributed generation.

The sixth myth, that *barriers to new and innovative energy technologies are primarily technical*, suggests that most people believe novel energy technologies fail to thrive because they are not technically sound. To deflate this myth, Benjamin Sovacool and Richard Hirsh explore the nontechnical (e.g., political, social, economic, and cultural) impediments to the widespread use of innovative, small-scale energy technologies, such as distributed generation (reciprocating gas engines, micro-turbines, combined heat and power systems) and renewable energy systems. The authors conclude that many novel energy technologies are feasible in the sense that they can operate reliably and produce power economically. But to become extensively adopted, they must overcome utility reluctance, public misinformation, and historical attitudes about power production and consumption. By emphasizing the importance of technical challenges, this myth directs attention away from what Ben Sovacool and Richard Hirsh argue are the more important nontechnical obstacles.

The seventh myth is that *renewable energy systems could never fill the need for growing electricity demand in America*. Rodney Sobin disputes the widespread notion that renewable energy resources are insufficient or too diffuse to meet a large proportion of U.S. electricity demand. In contrast, the chapter makes the case for renewably generated electricity, and focuses in particular on how their prospects are likely to brighten as renewable technologies advance and the environmental, health, security, and other costs of fossil-based energy become more apparent. The chapter explores the renewable energy resource base, trends and advances in pertinent technologies, and costs, including externalities, associated with electric power generation. The chapter also discusses relevant policy options and implications, since the fate of this myth depends largely on whether or not future policies reward the environmental and security benefits of renewable resources.

The eighth myth is that *power systems are economically and environmentally optimal*. In discussing this myth, Tom Casten and Robert Ayres describe four broad causes of power problems in the United States. First, the system fails to recycle waste energy from power generation or from industrial processes. Secondly, rules and regulations predicated on yesterday's technology, block innovation. Thirdly, regulations largely prevent energy recycling plants (local power) from capturing the benefits such generation creates for society. Finally, universal subsidies to central power disadvantage local power development. The United States power system is not optimal. Heat is seldom recycled. With local generation largely blocked, the U.S. power industry satisfies electric load growth by building new central plants and new transmission, which require more than twice as much capital as local generation. The expensive new central plants then burn twice as much fossil fuel as would be burned by an economically optimal system. This exacerbates environmental and balance of payments problems and leaves the power system needlessly vulnerable to extreme weather events and terrorists. After explaining the myth that the power system is optimal, the authors recommend removing various barriers to local generation that recycles waste energy.

The next three myths pertain to the potential role that *energy efficiency* could play in meeting the nation's energy needs. They address the beliefs that energy efficiency is "tapped out" already; that energy efficiency measures are unreliable, unpredictable, and unenforceable; and that government energy R&D takes decades to pay off, if ever.

The ninth myth is that *energy efficiency improvements have already reached their potential*. In this chapter, Amory Lovins discusses some of the economic, political, and social impediments to energy efficiency practices, before arguing that an immense amount of energy efficiency potential still exists. Overall, the U.S. now uses 43% less energy per unit of economic output than it did 30 years ago, cutting today's energy costs by a billion dollars a day – like a huge universal tax cut that also cuts the federal deficit. However, tremendous opportunities remain. Much of the waste heat thrown away by U.S. power stations – a fifth more energy than Japan uses for everything – could be lucratively recovered and reused if combined heat and power were encouraged as it is in Europe. Converting coal at the power plant into incandescent light in the room is only 3% efficient, and a dozen huge power plants spew out CO_2 just to run U.S. equipment that is turned off. If energy efficiency has so much potential, why hasn't it already been done? Naïve economic models assume free markets so perfect that any cost-effective efficiency investments must already have been made. The opposite is true: most remain untapped, yet the myth that energy efficiency is "tapped out" leads people to underestimate how much energy they can save. Thirty years of experience has revealed that efficiency has numerous obstacles – perhaps 60–80 market failures – each convertible to a business opportunity.

The tenth myth is that *energy efficiency measures are unreliable, unpredictable, and unenforceable*. Edward Vine, Marty Kushler, and Dan York challenge those who believe that energy efficiency cannot be relied upon as a utility system resource. This myth has been around for a long time and continues to surface periodically, despite contrary evidence and rebuttals from industry analysts. The chapter begins by reviewing the concepts of reliability, predictability, and enforceability within the context of utility system planning and operations, including the risks and uncertainties of expanding electricity generation, transmission and distribution and the risk-management benefits of energy efficiency. Recent regulatory activities are highlighted that promote energy efficiency explicitly for its risk-reduction value in resource procurement. The chapter also reviews the experience of evaluating energy efficiency programs and technologies in the last 20 years, the development and implementation of evaluation protocols, key findings resulting from the evaluation of energy efficiency programs, and methods for ensuring and enforcing the performance of energy efficiency measures, programs, and portfolios. Unlike this prevailing myth, energy efficiency programs are sufficiently reliable, predictable, and enforceable to allow demand-side management to be incorporated as a utility system resource.

In discussing the eleventh myth, that *energy R&D investment takes decades to reach the market*, Dan Kammen and Greg Nemet examine investments in R&D in the energy sector and observe broad-based declines in funding since the mid-1990s. The large reductions in investment by the private sector should be a particular area of concern for policy makers. Multiple measures of patenting activity reveal widespread declines in innovative activity that are correlated with R&D investment – notably in the environmentally significant wind and solar areas. These areas are also used to illustrate that the market has not been slow to act on energy innovations. Against this disappointing background, however, they find that when investments are made, they consistently pay off. Across the spectrum of energy technologies, innovations lead to improved technologies reaching the market, in some cases virtually instantly. Drawing on prior work on the optimal level of energy R&D, Dan Kammen and Greg Nemet identify a range of values which would be adequate to address energy-related concerns. Comparing simple scenarios based on past public R&D programs and industry investment data indicates that a 5 to 10-fold increase in energy R&D investment is both warranted and feasible. Most importantly, the history of investments resulting in marketable technologies suggests that this investment would result in near-term returns to both individual companies and society as a whole.

The final two myths address *environment quality* issues. Together, these chapters articulate and debunk myths about the cost of addressing global warming and the involvement of the developing world in taking corrective actions. Together, these chapters document the environmental damage resulting from today's methods of producing and using energy and suggest alternative ways of tackling these problems.

The twelfth myth purports that *addressing global warming will bankrupt the U.S. economy*. In this chapter, Eileen Claussen and Janet Peace maintain that this myth is based primarily on imperfect economic models, which often yield results that suggest *any* climate policy is too expensive. They discuss why postponing the implementation of climate policy makes the problem larger, increases the costs to future generations, and increases the risk of severe climate related damages. Recognizing that a long-term approach emphasizing low carbon technology is needed, they maintain that we must begin today with a suite of climate focused policies that will provide a bridge to the time when new lower-carbon-emitting large-scale technologies can be put into use. Policies that focus exclusively on solving climate change with a next generation of technology will not encourage the more cost-effective actions that can be taken today – namely conservation and energy efficiency. Taking action now to conserve energy and invest in efficiency saves consumers and businesses money, puts downward pressure on energy prices, helps decrease our reliance on foreign oil, helps to reduce other types of air pollutants, and generally strengthens the economy overall (since reducing the amount we spend on energy will allow capital to be invested elsewhere).

The thirteenth myth is that *developing countries are not doing their part in responding to concerns about climate change*. In his chapter, Tom Wilbanks refutes the prevailing myth that developing countries are not doing their part in addressing energy-related concerns about global climate change. Determining what their part should be depends on such issues as equity and sustainable development, since human driving forces underlying the problem came from developed countries. In the meantime, however, even though they are not explicitly a part of the Kyoto Protocol, in many cases developing countries are actively involved in discussions of global responses, and in some cases they are global leaders in demonstrating important clean energy alternatives and considering adaptation as an aspect of integrated responses. Their recent patterns of response are important as sources of information about possible pathways for increasing their contributions in the future in ways that make sense for them. The myth that developing countries are not doing their part does not justify inaction by others.

1.5. CONCLUSIONS

While we have discussed 13 key myths and a galaxy of assorted misconceptions, this book does not claim to be comprehensive. For instance, we have not addressed the numerous myths surrounding nuclear power, coal mining and coal plants, carbon capture and sequestration, and demand-response technologies. Hopefully we have challenged readers to consider the many energy myths that impact society. We also hope that this book catalyzes a growing body of knowledge about energy myths and fosters a systematic approach to examining their implications.

The great diversity of energy myths – and the topics they cover – should remind us that the issues surrounding American energy policy influence a wide range of technologies, people, and institutions. Thus, they also shape the nation's perceived technological options, the social interests of stakeholders (utility managers, business leaders, system operators, consumers), and the stability of the natural environment. Yet since the options, interests, and impacts of different energy technologies can never be entirely predictable and absolute, a degree of uncertainty continues to endure regarding which energy pathways the country should pursue.

Within this range of uncertainty, it can become all too easy to support almost any hypotheses concerning energy and American society. In Arthur Conan Doyle's (1891, p. 43) *A Scandal in Bohemia*, Sherlock Holmes remarks that "it is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts." Analogously, G.K. Gilbert (1886, p. 22) once famously stated that:

> In the testing of hypotheses lies the prime difference between the investigator and the theorist. The one seeks diligently for the facts which may overthrow his or her tentative theory, the other closes his eyes to these and searches only for those which will sustain it.

It appears that the sheer complexity of the energy sector – and the seamless integration of energy with transportation, industry, agriculture, buildings, and various infrastructures – creates ample opportunity for the theorist to "search for only those facts" to support a given idea (Clark, 1990).

However, while we realize that our own work is laden with assumptions and preconceptions that are embodied in any examination of energy systems, we endeavor to be reflective of those. By debating a wide range of myths and tackling alternative views and interpretations of past, present, and future energy systems, we hope that there is literally something for everyone concerned with energy in this book. We emphasize that analysts and policymakers must expand their view of energy needs, services, and resources to incorporate social issues and behavioral, economic, and cultural factors. Only with such a broad scope of critical and insightful analysis can the role of future energy technologies by realistically examined. It is precisely this type of expansive investigation and critical thinking that we have attempted to adhere to in each of the chapters of this book.

REFERENCES

Ackerman, Eric: 2006, "Where Are We Headed? Life After the Energy Policy Act of 2005," *Presentation to the Edison Electric Institute*, [online] http://www.eei.org/meetings/nonav_2006-01-19-dm/EPACTpptJan06.pdf, accessed July 2006.

Adelman, M.A.: 1995, *The Genie Out of the Bottle: World Oil Since 1970*, MIT Press, Cambridge, MA, USA.

Bain, Read: 1947, "Man, the Myth-Maker," *The Scientific Monthly* 65(1), pp. 61–69.

Bidney, David: 1950, "The Concept of Myth and the Problem of Psychocultural Evolution," *American Anthropologist* 52(1), pp. 16–26.

Bidney, David: 1955, "Myth, Symbolism, and Truth," *The Journal of American Folklore*, 68(270), pp. 379–392.

Brandemuehl, Michael J.: 2005, "A Sustainable Energy Future Possible," *The Denver Post* (December 4), p. E4.

Brown, M.A., Antes, M., Franchuk, C., Koske, B.H., Michaels, G., and Pellegrino, J.: 2006, *Results of the Technical Review of the Climate Change Technology Program's R&D Portfolio*, Oak Ridge National Laboratory, Oak Ridge, TN, [online] http://www.ornl.gov/sci/eere/communications.htm, accessed June 21, 2006.

Campbell, Joseph: 1981, *The Mythic Image*, Princeton University Press, Princeton, NJ, USA.

(CDIAC) Carbon Dioxide Information Analysis Center: 2006, [online] http://cdiac.esd.ornl.gov/trends/emis_mon/stateemis/graphics/usacemissions.jpg, June 23, 2006.

Charnley, Susan and Bruce Engelbert: 2005, "Evaluating Public Participation in Environmental Decision-Making: EPA's Superfund Community Involvement Program," *Journal of Environmental Management* 77(3), pp. 165–182.

Clark, John G.: 1990, *The Political Economy of World Energy: A Twentieth Century Perspective*, University of North Carolina Press, Chapel Hill, NC, USA.

Costa, Arthur L.: 2006, "Five Themes in a Thought-Full Curriculum," *Thinking Skills and Creativity* 1(1), pp. 62–66.

Deffeyes, Kenneth S.: 2001, *Hubbert's Peak: The Impending World Oil Shortage*, Princeton University Press, Princeton, NJ, USA.

Doty, William G.: 1986, *Mythography: The Study of Myths and Rituals*, University of Alabama Press, Tuscaloosa, AL, USA.

Doyle, Arthur Conan: 1891, *A Scandal in Bohemia*, Penguin Press, New York, NY, USA.

[EEI] Edison Electric Institute: 2005, *EEI Survey of Transmission Investment: Historical and Planned Capital Expenditures (1999–2008)*, EEI, Washington, DC [online] http://www.eei.org/industry_issues/energy_infrastructure/transmission, June 22, 2006.

Edwards, Paul N.: 2003, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in Thomas J. Misa, Philip Brey, and Andrew Feenberg (eds) *Modernity and Technology*, MIT Press, Cambridge, MA, USA, pp. 185–226.

[EIA] Energy Information Administration: 2005a, *Annual Energy Review 2004*, DOE/EIA-0384 (2004), Washington, DC [online] http://www.eia.doe.gov/emeu/aer/, June 21, 2006, pp. 71–75.

[EIA] Energy Information Administration: 2005b, *Annual Energy Outlook 2005*, DOE/EIA-0383 (2005), Washington, DC [online] http://www.eia.doe.gov/oiaf/archive.html, June 22, 2006.

[EPRI] Electric Power Research Institute: 2003, *Electricity Technology Roadmap: Meeting the Critical Challenges of the 21st Century*, EPRI, Palo Alto, CA, USA.

Elliott, Brian: 1988, "Introduction," in Brian Elliott (ed.) *Technology and Social Process*, Edinburgh University Press, Edinburgh.

Elliott, R. Neal: 2005, "Statement Submitted for the Record: EIA 2005 Annual Energy Outlook." *Hearing Before the Senate Committee on Energy and Natural Resources*, U.S. Government Printing Office, Washington, DC, USA.

Foster, Harold M.: 1984, "The New Literacy: Television, Purveyor of the Modern Myth," *The English Journal* 73(2), pp. 26–30.

Gilbert, Grove Karl: 1886, "On the Validity of Scientific Hypotheses," *American Journal of Science* 31.

Gotesky, Rubin: 1952, "The Nature of Myth and Society," *American Anthropologist* 54(4), pp. 523–531.

Hyman, Stanley Edgar: 1955, "The Ritual View of Myth and the Mythic," *The Journal of American Folklore* 68(270), pp. 462–472.

Jaber, Jamal O., Mamlook, Rustom, and Awad, Wa'el: 2005, "Evaluation of Energy Conservation Programs in Residential Sector using Fuzzy Logic Methodology," *Energy Policy* 33(10), pp. 1329–1338.

Kay, Alan: 2006, *Contemporary Authors: The Biography of Alan N. Kay*, Thompson Gale, New York, NY, USA.

Kirk, Geoffrey: 1977, *Schumacher on energy: Speeches and writings of E.F. Schumacher*, Jonathan Cape, London, UK.

Koomey, Jonathan, Craig, Paul, Gadgil, Ashok, and Lorenzetti, David: 2003, "Improving Long-Range Energy Modeling," *Draft Report for Lawrence Berkeley National Laboratory* LBNL-52448, [online] http://eetd.lbl.gov/ie/pdf/LBNL-52448.pdf, accessed July 2006.

Kuklick, Bruce: 1972, "Myth and Symbol in American Studies," *American Quarterly* 24(4), pp. 435–450.

Leighninger, Matt: 2004, "The Seven Deadly Citizens: Moving From Civic Stereotypes to Well-Rounded Citizenship," *Good Society* 13(2), pp. 29–38.

Lenssen, Nicholas, Hanson, Sue, and Enbar, Nadav: 2006, "The Distributed Energy and Renewable Energy Outlook," *Presentation at the EPRI Solutions Outlook Conference*, Boulder, Colorado, CO, USA, May 18–19.

Levi-Strauss, Claude: 1955, "The Structural Study of Myth," *The Journal of American Folklore* 68(270), pp. 428–444.

Lovins, Amory, Datta, E. Kyle, Feiler, Thomas, Lehmann, Andre, Rabago, Karl, Swisher, Joel, Wicker, Ken: 2002, *Small is Profitable: The Hidden Benefits of Making Electrical Resources the Right Size*, Rocky Mountain Institute, Snowmass, CO, USA.

Lovins, Amory: 2005, "Statement Submitted for the Record: EIA 2005 Annual Energy Outlook," Hearing Before the Senate Committee on Energy and Natural Resources (February 3), pp. 93–96.

Malthus, Thomas: 1798, *An Essay on the Principle of Population*, Jay Johnson, London, [online] http://www.econlib.org/library/Malthus/malPop.html, accessed July 2006.

Masters, Gilbert M.: 2004, *Renewable and Efficient Electric Power Systems*, Wiley and Sons, London, UK.

Misa, Thomas J.: 2003, "The Compelling Tangle of Modernity and Technology," in Thomas J. Misa, Philip Brey, and Andrew Feenberg (eds) *Modernity and Technology*, MIT Press, Cambridge, MA, USA, pp. 1–32.

Morris, David: 2006, "The once and Future Carbohydrate Economy," *American Prospect* (April), p. A3.

Munz, Peter: 1956, "History and Myth," *The Philosophical Quarterly* 6(22), pp. 1–16.

Nelson, Gaylord: 1979, "Introduction," in Hugh Nash (ed.) *The Energy Controversy: Soft Path Questions and Answers*, Friends of the Earth, San Francisco, CA, USA, pp. 11–14.

Nimmo, Dan and Combs, James E.: 1980, *Subliminal Politics: Myths and Mythmakers in America*, Prentice-Hall, Englewood Cliffs, NJ, USA.

Nye, David: 1999, *Consuming Power: A Social History of American Energies*, MIT Press, Cambridge, MA, USA.

Palast, Greg, Oppenheim, Jarrold, and MacGregor, Theo: 2003, *Democracy and Regulation: How the Public Can Govern Essential Services*, Pluto Press, London, UK.

Porter, Theodore M: 1995, *Trust in Numbers*, Princeton University Press, Princeton, NJ, USA.

Rose, Nikolas: 1991, "Governing by Numbers: Figuring Out Democracy," *Accounting, Organizations and Society* 16(7), pp. 673–692.

Schrank, Jeffrey: 1973, "Mythology Today" *Media and Methods* 9 (April): 22–40.

Segal, Robert A.: 1980, "The Myth-Ritualist Theory of Religion," *Journal for the Scientific Study of Religion* 19(2), pp. 173–185.

Slotkin, Richard: 1987, "Myth and the Production of History," in Sacvan Bercovitch and Myra Jehlen (eds) *Ideology and Classic American Literature*, Cambridge University Press, Cambridge, pp. 70–90.

Smil, Vaclav: 2004, *Energy at a Crossroads: Global Perspectives and Uncertainties*, MIT Press, Cambridge, MA, USA.

Sovacool, Benjamin K.: 2006, "The Power Production Paradox: Revealing the Socio-technical Impediments to Distributed Generation Technologies," *Ph.D. Thesis*, Science and Technology Studies Department, Virginian Tech, Doctoral Dissertation, Blacksburg, VA, [online] http://scholar.lib.vt.edu/theses/available/etd-04202006-172936/, accessed July 2006.

Tickle, Louise: 2005, "Why Green May Not Mean Go," *The Guardian (London)*, November 12, p. 3.

Toulmin, Stephen: 1992, *Cosmopolis: The Hidden Agenda of Modernity*, University of Chicago Press, Chicago, IL, USA.

Watts, Alan: 1971, *W. Myth and Ritual in Christianity*, Beacon Press, London, UK.

Wheelwright, Philip: 1955, "The Semantic Approach to Myth," *The Journal of American Folklore* 68(270), pp. 473–481.

Williams, James C.: 2001, "Strictly Business: Notes on Deregulating Electricity," *Technology & Culture* 42, pp. 626–630.

Williams, Susan H.: 1986, "The Uses of Myth," *Journal of Law and Religion* 4(1), pp. 153–159.

Wise, George: 1985, "Science and Technology," *Osiris* 1, pp. 229–241.

Yergin, Daniel: 1991, *The Prize: The Epic Quest for Oil, Money, and Power*, Simon & Shuster, New York, USA.

Yergin, Daniel: 2006, "Ensuring Energy Security." *Foreign Affairs* 85(2), pp. 69–82.

CHAPTER 2

ENERGY MYTH ONE – TODAY'S ENERGY CRISIS IS "HYPE"

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There is a common belief in the United States that the marketplace, when left to its own devices, can meet society's needs. Often the technical solutions to societal problems already exist; all that blocks their usage are market imperfections that can be eliminated by simply updating public policies. When new technologies are needed, scientists and entrepreneurs have shown an impressive capacity to deliver them quite rapidly. How, then, can an energy crisis possibly be upon us? The fact is, the U.S. government and industry have invested a fraction of what has been needed to develop solutions to the nation's energy problems, and local, state, and federal policies and initiatives have been inadequate. As a result, options do not exist today to ensure a sustainable energy future, and the country faces the risk of a very real energy crisis.

Many commentators and policymakers deny the possibility of an energy crisis, instead contending that the energy challenges facing the country are fabricated, exaggerated, or simply wrong. For example, marketplace manipulation has been a common accusation by those who claim that today's energy crisis is a hoax. According to CBS News Correspondent Vince Gonzales, California's energy crisis – the blackouts and sky-high power prices that cost California billions of dollars in 2001 – was manufactured by key power companies hoarding energy supplies to make more money.

> Overall, the companies kept more than 30 % to 50 % of their power off the market. During some of the worst moments of the crisis, they held back even more – anywhere from 55 to 76 % of production – all in an effort, whistleblowers told CBS News more than a year ago, to cut the power supply and drive up prices.[1]

More recent allegations of market manipulation have been made against oil companies that have experienced record-breaking profits while Americans face record-breaking gasoline prices. In proposing legislation for an excess profits tax

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on "oil company profiteering," Congressman Dennis Kucinich from Ohio speaking from the Floor of the U.S. House of Representatives on April 26, 2006, stated that "By taxing excessive profits, it puts the breaks on price gouging and will lower the price of gasoline."[2] Similarly, the U.S. Justice Department has accused global energy giant BP of secretly cornering the propane market in 2004 by buying nearly all of the propane stored along a key Texas–New York pipeline. The case alleges that the market manipulation caused a 50% spike in propane prices at the height of the home heating season (Wilke and Cummins, 2006). The clarity of a long-term energy crisis is blurred by such supply and price distortions.

The notion of a contrived energy crisis has also been portrayed as a cover-up for pro-industry and anti-environmental policies. Consider a news story written shortly after the Administration released its *National Energy Plan* in 2001, when Anthony York (among others) suggested that the industry-friendly plan was written in response to a contrived energy crisis. York states that the Administration's "first domestic crisis is largely self-created. Despite Bush's rhetoric, it's not an energy crisis – experts disagree on whether, outside of California, we're really facing one – but a crisis of public confidence."[3] Similarly, Dan Ackman, an Editor for Forbes, describes "A phantom energy crisis: The Bush administration has convinced the nation that we're in the middle of a power emergency, but the facts indicate otherwise." He continues: "Cheney used to work in the energy business, as did the president, so they should know better. The crisis hype is phony. Is the administration talking up a crisis to help pay back its buddies in the oil business?"[4] Others have suggested that the energy crisis is simply a ruse for relieving pressure on environmental issues. "Is Bush Using a Phony 'Energy Crisis' for Cover on the Environment?" asks Frank Pellegrini in a story run by *Time Magazine* on May 22, 2001.[5]

Arguing that technical solutions can outpace society's energy challenges, science and technology champions have questioned the reality of an energy crisis. Such champions argue that any energy crisis facing society can inevitably be solved by human ingenuity and technological progress. Advocates of solar photovoltaics, natural gas pipelines, steam power, nuclear power and fusion technologies have each argued such systems could solve all of society's energy needs. For example, technology futurists argue that the energy in the jet stream winds located miles above earth is sufficient to supply all the world's energy needs. This energy, it is claimed, can be captured by tethered flying turbines using combinations of existing technology at economics calculated to be better than fossil fuel or nuclear power if all costs are considered. "Utilizing this energy can not only resolve our energy independence problems, but start putting a halt to our global warming problem."[6]

Similarly, Marty Hoffert (2006) – professor emeritus of physics at New York University – describes a range of visions for a renewable-energy future.[7] One of these involves photovoltaic panels positioned in geostationary orbit to receive constant sunlight and thereby furnish the earth with a reliable stream of electricity. This ring of sun-reflecting solar-powered satellites would use wireless transmission to beam electricity down to earth on a continuous basis, potentially meeting all of the earth's needs for power.

Energy resource analysts are often similarly optimistic. “There is no energy shortage,” says R. Martin Chavez, chief executive of Kiodex, which supplies software to companies for managing their exposure to energy costs. “There is so much oil and natural gas in the ground. There are more known reserves now than there ever has been.”[8] The argument of abundant energy resources has been applied often in characterizing the availability of unconventional petroleum sources such as tar sands and oil shale and with respect to unconventional natural gas resources such as methane hydrates. These methane-rich ice formations are found in seafloor sediments around the world and in the arctic permafrost. According to Lorie Langley, a researcher at Oak Ridge National Laboratory, “Estimates on how much energy is stored in methane hydrates range from 350 years’ supply to 3,500 years’ supply based on current energy consumption.…”[9]

In sum, the nation’s energy problems have been characterized as fabricated, exaggerated, and untrue. In contrast, this chapter argues that today’s energy situation is indeed of a “crisis” magnitude similar to the situation faced by the country in 1973–1974. Despite myths to the contrary, the health of the U.S. energy system heading into the 21st century is every bit as dire as it was 30 years ago. After a general overview of comparative statistics, five interconnected energy challenges are probed, comparing their conditions in 1970 with those of today. We begin by looking at the nation’s oil vulnerability. Attention then turns to the electric system, first considering the nation’s power plants and then turning to issues of the grid and other critical energy infrastructures. Next we consider the evolution of the demand sector, focusing especially on buildings, communities and aspects of the built environment that impact energy requirements. We end with a discussion of the link between energy and environmental quality. Thus, we generally track the dimensions of the Energy Sustainability Index (see Chapter 1). In general, this assessment leads to the conclusion that the nation has failed to meet its energy challenges in ways that auger well for the future.

2.1. THE ENERGY CRISIS: SOME COMPARATIVE STATISTICS

For energy analysts, the energy crisis of 1973–1974 was a watershed event. It came at a time when most Americans were oblivious to vulnerabilities in their electricity and gasoline supplies. This attitude changed dramatically beginning in 1973 when customers began experiencing electricity brown outs and rapidly rising fuel prices. In October, members of the Organization of Petroleum Exporting Countries (OPEC) instituted an oil embargo, cutting further into the supply of oil and resulting in fuel rationing and long lines at gasoline stations. As the embargo continued through 1974, the U.S. economy weakened with high rates of inflation and unemployment (EIA, 1998). In real terms, crude oil prices rose from $11.55 per barrel in chained (2000) dollars in 1970 to $19.78 in 1974 (EIA, 2005a, p. 167). The average retail price of electricity for all customers rose in real terms from 6.2 cents per kWh in 1970 to 7.2 cents in 1974 (EIA, 2005a, p. 259).

Oil prices remained high through the mid-1980s reaching a peak of $53.74 per barrel in 1981 (EIA, 2005a, p. 167). During this period, markets responded: domestic oil production increased and energy end-use efficiency improved. But once oil prices collapsed in 1986, American oil production fell, the share of imports began to rise rapidly, and the pace of efficiency gains slowed. Improvements to the nation's energy security have been sluggish since then. This malaise is surprising in light of the many energy disasters experienced over the last several decades: the 1979 Three-Mile Island nuclear accident, the 1989 *Exxon Valdez* oil spill, the California electricity crisis of 2001 and 2002, the 2003 Northeast blackout, and the oil price spikes resulting from Gulf Coast hurricanes in 2005. In addition, the September 11, 2001, attack underscored the vulnerability of the nation's critical energy infrastructure to terrorists. Only with escalating oil prices beginning in 2004 has the American public rekindled its interest in energy issues.

The number, range, and severity of these energy catastrophes seem to have grown along with the economy's increasing dependence on the continuous supply of reliable power and fuel. Back in 1970, there were no personal computers or cellular phones, and the Internet was just being invented. Factories mass-produced goods that were shipped to warehouses where large inventories were kept for future delivery based largely on mail orders. Today's fast-paced information economy is inextricably tied to reliable power. Our just-in-time manufacturing supply chain depends on an ever-increasing fleet of trucks poised for immediate delivery in response to satellite-based cell-phone orders and high-speed Internet communications. These critical interdependencies require greater levels of energy reliability, security, and affordability than ever before.

Yet the U.S. energy sector today faces many of the same problems that existed 30 years ago, while at the same time it confronts new challenges. Today's difficulties include rising energy prices related to disruptions and interruptions in fuel supply; congested energy distribution networks; energy-inefficient buildings, communities, manufacturing, and transportation; persistent air pollution problems, and rising greenhouse gas emissions (Interlaboratory Working Group, 2000; DOE, 2002; NCEP, 2004).

The nation has made remarkable progress in modernizing many aspects of its energy system. Utilizing advances from the aeronautics industry, efficient gas turbine technology has come to dominate new power plant designs. Existing nuclear plants have achieved record output levels and capacity factors, and hydropower and bioenergy have grown since 1970. While overall energy consumption has increased from 68 quads in 1970 to 100 quads in 2004 (EIA, 2005a, Table 1.5, p. 13), the United States now uses 45% less energy per unit of economic output than it did 35 years ago, saving consumers approximately one billion dollars a day through lower utility bills.

On the other hand, the electric generation system continues to operate at the same 33% efficiency level that it has for more than a half century.[10] The transmission cables used to transport power are 1950s technology with significant resistance losses[11] and capacity constraints. The nation remains without an operating repository

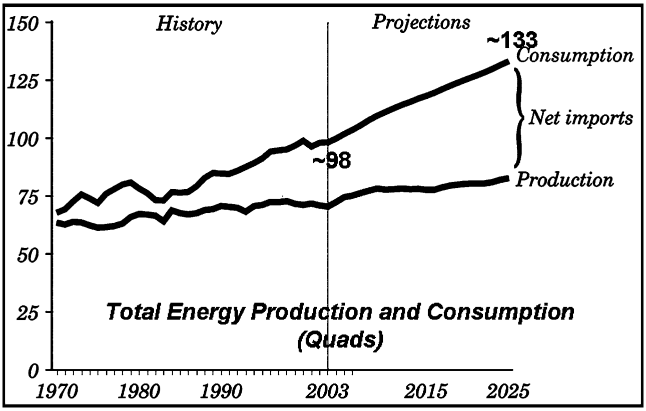

Figure 2.1. Total U.S. energy production and consumption (in Quads) (Adapted from EIA, 2005b, Fig. 6, p. 7

for its nuclear wastes, which is a significant barrier to construction of new nuclear plants. Greenhouse gas emissions continue to increase, global temperatures are rising, and air pollution threatens human and ecosystem health. The fuel economy of cars has been unchanged for almost two decades, and the nation's transportation system remains almost entirely (98%) dependent on petroleum. Finally, U.S. energy production has increased modestly from 70 quads in 1970 to only 80 quads in 2003, creating a large and growing dependency on energy imports, especially oil (Figure 2.1). Thus, the nation has not responded with robust solutions to the energy crises and disasters of the past 30 years. Many analysts believe that the nation must begin transforming its energy system over the next 30 years to deal with emerging fossil energy constraints and global climate change.

Over the next 30 years, the U.S. population and economy are projected to grow significantly – from a population of 203 million in 2004 to 378 million by 2035 (U.S. Census Bureau, 2004). This growth will require a significant increase in the U.S. building stock, in industrial, business and commercial activities, and in transportation infrastructure – all with corresponding energy use. The EIA forecasts that in 2030 the United States will consume 134 quads – one-third more than we use today (Figure 2.1). It's hard to see how this rate of growth in energy consumption can be sustained.

2.2. PERSISTENT OIL VULNERABILITY

The 1973–1974 Arab oil embargo was the first oil supply disruption to cause major price increases and a worldwide energy crisis. Supply disruptions have continued and they are likely to increase in severity if spare oil production capacity continues to shrink and production remains concentrated in unstable regions of the world.

In 1990, when Iraq invaded Kuwait, OPEC had roughly 5.5 million barrels a day (MBD) of spare capacity, enough to replace the oil from those two countries and to supply about 8% of global demand. Today, OPEC's spare capacity stands at only 2% of world demand with 90% of this capacity under the control of Saudi Arabia (National Commission on Energy Policy, 2004). The rapidly growing demand for oil by China and India to fuel their expanding economies has placed unprecedented pressure on the world supply of oil (and other basic materials like concrete, aluminum, and steel), and has driven crude oil prices up to $70 per barrel and higher. The fact that spare capacity is both extremely limited and concentrated in one region leaves world oil markets extremely vulnerable to short-term disruptions. This situation is not likely to improve in the near term since almost half of the world's proven reserves of conventional oil are located in Saudi Arabia, Iraq, and Iran.

Over the last 30 years, the United States has sought to improve oil security by promoting a greater diversity of world oil suppliers, creating the largest dedicated strategic petroleum reserve in the world, and reducing domestic consumption through Corporate Average Fuel Economy (CAFE) standards. CAFE standards helped raise average new passenger vehicle fuel economy from 15 to 27.5 mpg between 1974 and 1987, while at the same time vehicle performance and safety improved. As a result of these policies and due to structural shifts away from energy-intensive industries, the U.S. economy today is less oil-intensive than it was in 1970. The ability of the U.S. economy to weather oil price shocks improves as oil's share of GDP decreases. In 1970, the country consumed 1.33 barrels of petroleum for every $1000 of GDP (in chained 2000 dollars). By 2004 that number had been cut almost in half to 0.67 barrels of petroleum per $1000 of GDP (EIA, 2005a, Table 5.13c, p. 154 and Appendix D, p. 373).

Despite this progress, the United States is as vulnerable today to oil supply disruptions and price spikes as any time in the past. It has grown to become the world's largest oil consumer by a considerable margin, while at the same time its domestic oil production has shrunk. Oil imports have filled the expanding gap and now account for 58% of total U.S. oil consumption – up from 22% in 1970 (EIA, 2005a, Table 5.7).

To obtain a sense of the consequences of a disruption in such a constrained world oil market, the National Commission on Energy Policy, a bipartisan group of 16 of the nation's leading energy experts, simulated an "oil supply shockwave" in 2005. The simulated shockwave was precipitated by three hypothetical events that removed 3 MMBD from the world's market of oil: unrest in oil-producing Nigeria, an attack on an Alaskan oil facility, and the emergency evacuation of foreign nationals from Saudi Arabia. As result of these events, the price of gasoline in the U.S. rose to $5.75 per gallon, two million people lost their jobs, and the consumer price index jumped 13%. Worse, panelists who participated in the oil supply shockwave including Senators Richard Lugar and Joseph Lieberman, concluded that nothing could be done to avoid these impacts after the disruptions began.[12]

U.S. oil vulnerability has been aggravated by the stagnating fuel economy of U.S. cars. CAFE standards peaked in 1985 at 27.5 mpg for cars and the standards were raised only slightly in 2005 to 22.2 mpg for light-duty trucks, including the expanding fleet of SUVs. For the past two decades technology advances such as front-wheel drive transmissions, electronic fuel injection, enhanced power-train configurations, and computer-controlled engines have allowed consumers to buy larger and more powerful cars; they have not been used to produce better gas mileage. As a result, new vehicle fuel economy is now no higher than it was in 1981, but vehicle weight has increased by 24% and horsepower has almost doubled (NCEP, 2004, p. 7). In addition, Americans are driving more miles: over the past decade, vehicle miles traveled have increased by close to 3% each year.

Hybrid electric vehicles (HEVs) and advanced diesel technologies offer opportunities to improve fuel economy without sacrificing size or power. Hybrids, in particular, are potential "game changers" because they are already in the marketplace and they achieve substantial fuel economy without reducing horsepower. Plug-in HEVs offer the prospect of even greater oil savings by driving all-electric for the first 20 to 60 miles (depending on advances in battery performance), before deploying the internal combustion engine. Still, global oil consumption is forecast to grow by 50% by 2025. Even with hybrid technologies, it is not clear how long the world can produce enough oil to meet this growing demand.

Cellulosic ethanol and diesel from biomass and wastes will be needed to diversify and expand the nation's transportation fuels. Despite efforts since the late 1980s, nonpetroleum fuels (mostly natural gas, corn ethanol, and electricity) still account for only 3.9% of the energy consumed by the U.S. transportation sector (EIA, 2005a, Table 2.1e, p. 42) – down from 4.9% in 1970. Cellulosic ethanol (made from fibrous or woody plant material, rather than corn) looks promising for the near- to mid-term as a means of reducing oil imports, cutting greenhouse gas emissions, and shoring up rural economies. With steady progress to reduce costs and improve yields, cellulosic ethanol could displace a large fraction of U.S. oil consumption without constraining food production. The major technical challenge is to find enzymes that can break down the cellulose into sugars and to identify the microorganisms that can digest the sugars to produce ethanol. In addition, new technologies show promise for converting organic matter, including animal and crop wastes, into clean diesel fuel. All of these options are critical to achieving a secure energy future, as is the development of unconventional petroleum resources.

2.3. POWER PLANT PROBLEMS: NEW AND OLD

The United States is increasingly dependent on electricity to meet consumer, business, and industrial needs. As a fraction of U.S. energy use, electricity has grown from 25% in 1970 to 40% today. The nation generates and consumes about 150% more electricity today than it did in 1970. The Energy Information Administration forecasts that U.S. electricity use will increase at a rate of 1.6% annually through 2030 (EIA, 2006, p. 147). Though much lower than the 7% annual growth rate experienced before the 1973 energy crisis (Hirsh, 1999), the current rate still would require a doubling of electricity production in about 40 years.

Unlike the transportation sector, which has grown similarly in energy use but continues to rely almost entirely on petroleum, the fuels and technologies used to generate electricity have changed substantially. In 1970, coal was the dominant fuel (as it is today) generating 46% of U.S. electricity; natural gas and hydropower were also important contributors (as they are today). Key differences are that only 1% of the nation's electricity came from nuclear power, there was essentially no power from renewables other than hydropower, and 12% was generated from burning oil. In 2004, coal produced 50% of U.S. electricity, nuclear electric power generated 20% and non-hydro renewables generated 2% (mostly wood and waste combustion but also some geothermal, wind, and solar), while only 3% was generated from burning oil (EIA, 2005a, p. 228). Thus, we have seen the rise of nuclear power, the displacement of petroleum-based electricity, and the emergence of several renewable technologies. These trends contribute favorably to oil security but they have created a host of security issues surrounding nuclear power including proliferation and nuclear waste storage (NCEP, 2004).

Additional concerns over power production are emerging. Recent investments in electric sector generation capacity have been in natural gas combustion turbines or combined cycle equipment (Figure 2.2). Natural gas combined cycle generators have been cheaper and faster to build than conventional coal plants and produce fewer emissions. The result has been the addition of over 150 GW of gas-fired power generation between 1999 and 2004. This surge in demand for natural gas is coming at a time when domestic natural gas production has begun to plateau

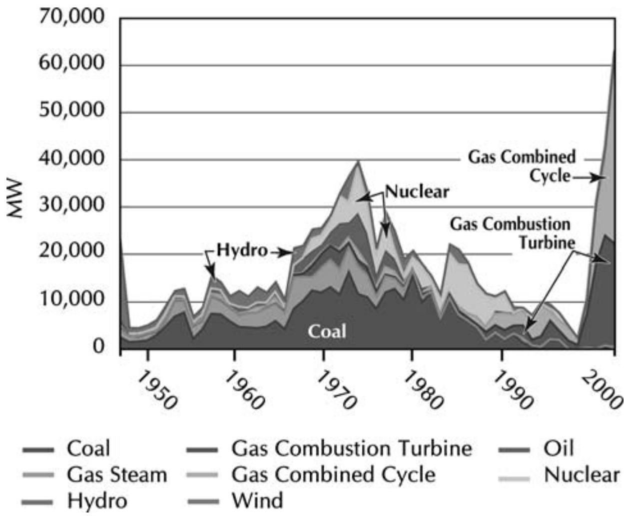

Figure 2.2. Investments in electric sector generation capacity (Revised from: NCEP, 2004, Figure 4.3, p. 44)

(NCEP, 2004). Looking to the future, most U.S. coal plants today are 20–50 years old (Morgan et al., 2005), and many of them are likely to be replaced by natural gas-fired generation (Figure 2.3)

Already, energy analysts see problems with this trend. The unprecedented investment in natural gas-fired electric capacity in recent years will significantly impact demand for the fuel. Natural gas imports have grown from 3.6% of U.S. natural gas consumption in 1970 to 15.3% in 2004 (EIA, 2005a, Table 6.1, p. 185). The National Petroleum Council predicts that North American sources will be able to satisfy only 75% of domestic demand for natural gas, and that imports will have to grow (National Petroleum Council, Committee on Natural Gas, 2003). Questions of natural gas security are likely to emerge as imports begin to follow in the footsteps of petroleum markets – accounting for an increasing proportion of U.S. energy consumption.

Natural gas markets have responded to the emerging gap between projected demand and available domestic supplies with a series of price increases for natural gas along with increased price volatility. This has already caused economic downturns for industries that are heavily reliant on natural gas. In addition, failure to address the mounting imbalance between the nation's demand and supply of natural gas will have negative environmental consequences. Natural gas has been seen by many as the fuel that will bridge the U.S. to a cleaner hydrogen-based or renewable energy future. Recent price spikes for natural gas may reverse this trend and result in the increased consumption of coal (NCEP, 2005). Aggravating this is the possibility that today's nuclear power plants could gradually be retired over the next 50 years if current licenses expire – depriving the nation of one of its key non-carbon energy sources.

Since the United States has the largest proven coal reserves of any nation in the world, coal clearly needs to continue to play a key role in powering the U.S. economy (Figure 2.4). However, coal's low efficiency of power conversion, high carbon content, and cost of pollution abatement pose challenges and perhaps explain why so few new coal plants have been built in the past decade (Figure 2.2).

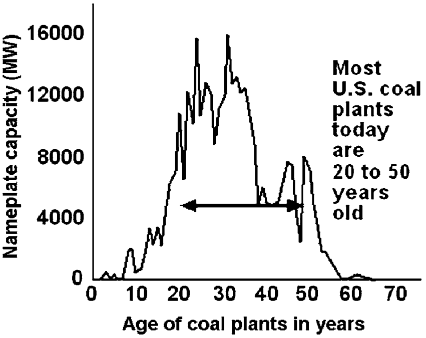

Figure 2.3. Age of U.S. coal plants 2004 (Adapted from Morgan et al., 2005, Figure 20, p. 55)

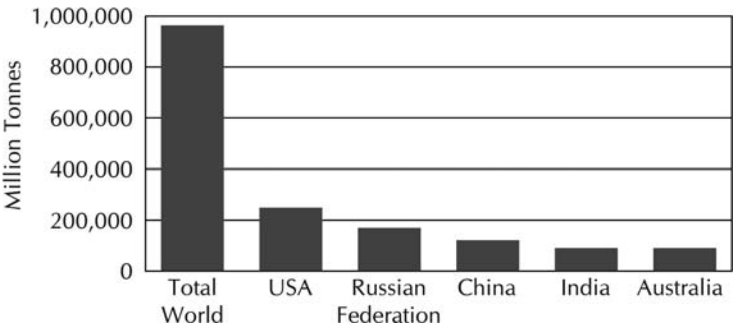

Figure 2.4. Proved coal reserves (Revised from: NCEP, 2004, Figure 4.6, p. 51)

Coal-based integrated gasification combined cycle (IGCC) technology opens the door to clean coal electric power and carbon capture. IGCC involves first converting coal into a synthetic gas using a chemical process. The syngas in turn fuels a combustion turbine and the exhaust heat is employed to produce steam for further power generation. The gasification process offers the potential for cost effectively isolating and collecting impurities as well as a large portion of the carbon. The cost premium of this process undermines its growth in the marketplace, which is why the Energy Policy Act of 2005 provides up to $800 million in investment tax credits for IGCC plants.

What about other sources of power? Because of security problems related to fuel sources and waste disposal, as well as potential public opposition, new nuclear plants cannot be counted on for widespread near-term use. Non-hydro renewable technologies, on the other hand, show great promise, even though their current market penetration is limited to only 2% of electricity generation.

Partly as a result of federal and state efforts to promote them, the cost of non-hydro renewables (such as biomass, geothermal, wind, and solar), has fallen dramatically over the last three decades. For instance, the cost of wind power has declined over 80% since 1970 as experience has grown and technologies have improved; costs now range from 4 to 6 cents/kWh (DOE/EE, 2004), which is nearly cost-competitive with natural gas and coal-produced power in the United States. However, the intermittent nature of wind resources is a barrier to its use in power system operations compared with firm power that can be produced on demand from traditional generation facilities. The cost of electricity from grid-connected photovoltaic systems has also dropped, but at roughly 20–25 cents/kWh today (NCEP, 2004) it remains significantly more expensive than other sources of grid-connected power. For non-hydro renewables to play a large role in primary power generation, further technological and cost breakthroughs or fiscal incentives will be needed.

The Energy Policy Act of 2005 provides a 2-year extension of the production tax credit (PTC) of 1.8 ¢/kWh for renewable facilities brought into production before the end of 2007 for their first 10 years of power generation. Current government forecasts project non-hydro renewables will increase from 2.2% of total power generation in 2004 to 4.3% in 2030, bolstered by technology advances and State and Federal incentives including the extended PTC (EIA, 2006, p. 81). Biomass, wind, and geothermal are expected to account for the bulk of these increases. Despite this rapid pace of growth, each of these three renewable resources is still projected to account for less than 2% of total generation in the year 2030.

Because of all of these issues, the Electric Power Research Institute (EPRI), a utility-sponsored think-tank, has concluded that "[t]he U.S. electricity enterprise is far from ready for the demands of the coming digital economy, an ever more competitive world, and its endangered environment" (EPRI, 2003).

2.4. THE FRAGILE ENERGY INFRASTRUCTURE

Nearly all primary energy sources require complex and expensive infrastructure to transform them into useful forms and to deliver them to markets. Oil must be extracted, shipped, refined, piped, and hauled before it can be used as a transportation fuel. Natural gas and coal must be extracted, processed, piped, transported by rail or barge, or otherwise delivered before they can be used to generate electricity, heat homes, and fuel industry. Once electricity is generated, it must be instantaneously moved on interconnected transmission and distribution grids to users. In addition, spent fissile materials, fly ash, and other waste streams must be managed at each step of the supply chain.

Siting nearly all types of major energy infrastructure has always been difficult. In 1970, however, the public was less hostile to locating critical energy infrastructure near to highly populated regions or in environmentally sensitive areas. The Three Mile Island and *Exxon Valdez* accidents had not occurred, the U.S. Environmental Protection Agency was just being established, and terrorist attacks did not feature prominently in risk assessments.

Today's energy infrastructure is much more extensive and varied than in the past, and additions to it often engender public resistance. Today's energy landscape includes nuclear plants and waste repositories, liquid natural gas (LNG) terminals, windfarms, and solar towers – all of which are new to the American scene since 1970. In addition, the environmental regulations controlling the siting and operation of critical energy infrastructure were in their infancy 30 years ago, but are now well-honed. These are deployed by a public that is increasingly unwilling to accept the construction of energy projects in its communities and states as evidenced by resistance to the Yucca Mountain nuclear repository, the Cape Wind project in Nantucket Sound, landfill gas generators proposed in many regions, LNG terminals proposed in Maine and New Jersey, and the proposed underwater transmission line from Connecticut to Long Island. Nuclear plants and hydroelectric dams have been the object of public concern, and several have been closed over the past decade. At the same time, there is a growing need to add energy infrastructure to economically and reliably meet business and consumer demands. The result is that today's energy infrastructure needs modernization and expansion, which was a major theme of the

2001 National Energy Plan (National Energy Policy Development Group, 2001) and has become the current focus of the National Commission on Energy Policy. In its 2006 report on *Citing Critical Energy Infrastructure*, the Commission notes that processes in which local concerns trump broader regional or national objectives has meant that:

> energy infrastructure has not always been proposed or built where it is needed most, or most urgently; extraordinary efforts have often been required to get facilities permitted in a timely fashion; and regulatory uncertainty and resulting delays have raised the cost of facilities themselves, along with delivered energy prices.
>
> (NCEP, 2006, p. 1).

Looking to the next 30 years, nearly every region of the United States will require new energy infrastructure as the national energy system expands and modernizes (Figure 2.5). As oil and natural gas imports increase, vulnerabilities associated with international shipments may grow and port facilities will need to be expanded and made more secure. Numerous new liquid natural gas terminals, thousands of miles of new transmission lines, and entirely new carbon sequestration sites, bioenergy refineries, and hydrogen storage and pipeline infrastructure may all be required. If permanently sequestering carbon from coal plants is to play an important role in the future, carbon storage sites will be needed. Potential repositories include depleted oil and gas fields, unmineable deep coal seams, or deep saline formations, and basalts. Each geologic formation presents unique challenges and will require considerable public review before large-scale sequestration occurs. All of these

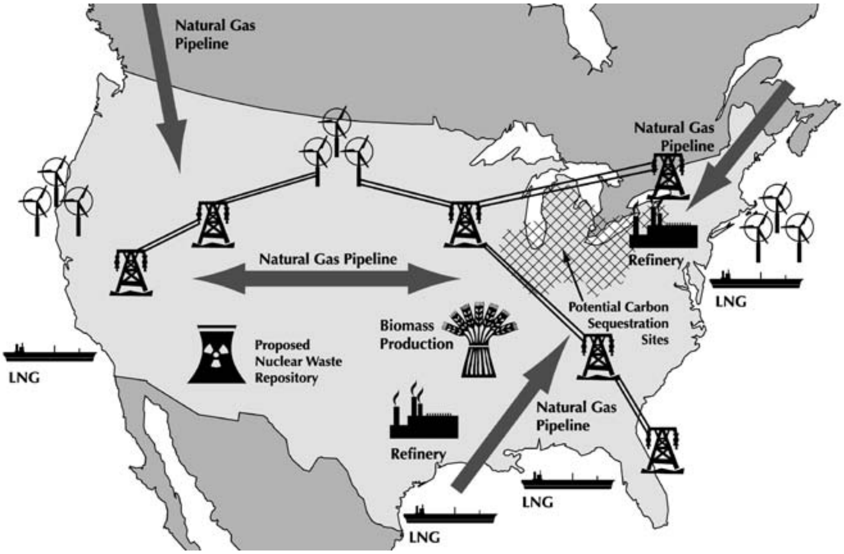

Figure 2.5. Major national energy infrastructure needs (NCEP, 2004, Figure 5.1, p. 85)

systems must now be resilient not only to operator error, equipment failures, and extreme weather, but also to the potential for malicious interference or attack.

One of the most highly stressed energy infrastructures in the nation is its high voltage transmission grid. The rapid growth of electricity demand over the past 30 years has contributed significantly to this infrastructure vulnerability because the growth in electricity production investment has not been accompanied by a proportionate growth in transmission investment. U.S. expenditures in transmission infrastructure peaked at almost $10 billion in 1970, but declined to a low of $2.2 billion in 1998 (in 2003$) (EPRI, 2003, pp. 2–4). The trend of declining transmission investment appears to have reversed since then, with $3.8 billion spent in 2002 and $4.1 billion in 2003 (Brown, 2003; Edison Electric Institute, 2005, pp. 1–3); however, many analysts believe more investment is necessary to transmit power to the growing wholesale and retail markets that have been created since utility industry restructuring (Hirst, 2004).

The Energy Policy Act of 1992 in combination with FERC Orders 888 and 889 caused increased utilization of the grid coupled with the removal of incentives to invest in grid improvements (Silberglitt et al., 2002, pp. 8–12). As a result, U.S. transmission capacity normalized by summer peak demand (measured in MW-miles/MW demand) has decreased – by 21% between 1989 and 2002 according to Hirst (2004, Table 4), and generating capacity margins (the % by which planned generating capacity resources are expected to be greater than expected peak demand) have decreased for the summer peak period from 21.6% in 1990 to 19.2% in 2004 (EIA, 2005a, Table 8.12, p. 267). The result has been reduced power reliability in many regions of the United States, with grid components being operated closer to their technical limits and beyond their originally planned lifetimes. The Energy Policy Act of 2005 includes several provisions to help with transmission expansion, including simplification of the transmission planning and permitting process, development of national transmission corridor permits, and incentives to increase investment in transmission lines.[13]

One trend emerging since 1970 that may lead to improved grid reliability is the development of distributed energy resources (DER). DER involves small power generation or storage systems located close to the point of use by consumers. They provide fuel flexibility, reduced transmission and distribution line losses, enhanced power quality and reliability, and more end-user control. While some distributed energy equipment produces significant air pollution including diesel-generator sets, other distributed generation technologies offer significant potential for reduced emissions of local air pollutants and CO_2, partly because of their higher efficiencies through cogeneration and partly through their use of on-site renewable resources and low-greenhouse gas (GHG) fuels such as natural gas. Because photovoltaic systems have production profiles that are highly coincident with peak demand, they can contribute significantly to grid stability, reliability, and security. Many experts believe that these various potential advantages will bring about a “paradigm shift” in the energy industry, away from central power generation to distributed generation.

Some distributed generation technologies, like photovoltaics and fuel cells, can generate electricity with no, or at least fewer, emissions than central station fossil-fired power plants. Total emissions can also be reduced through distributed generation using microturbines and internal combustion engines, if the waste heat generated is usefully employed on site to improve overall system efficiency. Based on the remaining technical potential for cogeneration in the industrial sector alone, it is estimated that nearly 1 quad of primary energy could be saved in the year 2025 (Worrell et al., 2004). Packaged cogeneration units that include cooling capabilities (and are therefore more attractive to commercial building operators) are projected to save 0.3 quads in 2025 (Hadley et al., 2004).

In 1970, distributed generation was limited to a small number of back-up diesel generators used to provide secure power. Since then, markets for DER have grown in size and diversity; today's customers include hospitals, industrial plants, Internet server hubs, and other businesses that have high costs associated with power outages. Markets are likely to grow as wealth increases and more consumers are willing to pay to avoid the inconvenience of blackouts. Smaller niche markets are growing where distributed energy resources are used as a stand-alone power source for remote sites, as a cost reducer associated with on-peak electricity charges and price spikes, and as a way to take advantage of cogeneration efficiencies. Distributed generation could be particularly advantageous in newly settled areas by reducing transmission line requirements, and by being more responsive to rapidly growing demand for power. Over the next half-century, it is possible that the demand for ultra-reliable power service will increase far more rapidly than the demand for electricity itself. This demand could be met, at least in part, by distributed energy resources.

2.5. UNTAPPED ENERGY EFFICIENCY POTENTIAL

It would be wasteful for the nation to rely entirely on new energy supplies to "build" its way out of its energy predicament. Curbing the demand for energy by using energy resources more efficiently is an important companion strategy. Many argue that energy efficiency is the fastest, cheapest, and cleanest national energy resources. However, while this resource has played an important role in the past, its current potential is not being adequately tapped due to numerous obstacles and inadequate policies (Brown, 2004).

Before the 1973–1974 Arab oil embargo, U.S. energy consumption grew in lock step with the nation's GDP. Measured in terms of energy consumption per dollar of GDP, the energy intensity of the nation remained constant. Economic growth appeared to dictate greater energy consumption.

The trend changed in the 1973–1986 period of rapidly rising energy prices when the economy (as measured by GDP) grew by 35% while U.S. energy consumption remained unchanged at 74 quads. As a result, the energy intensity of the economy dropped considerably (Figure 2.6). People purchased more fuel-efficient cars and appliances, insulated and weatherproofed their homes, and adjusted their thermostats

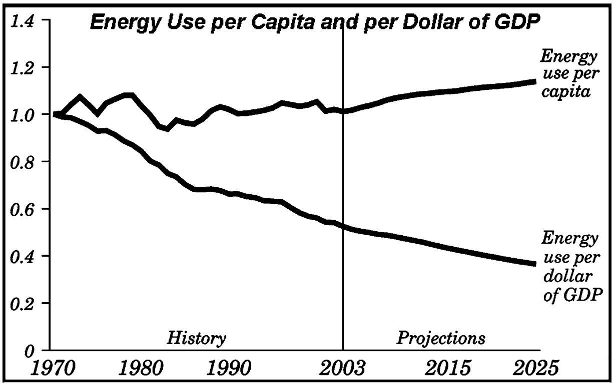

Figure 2.6. Energy use per capita and per dollar of GDP, 1970–2030 (index, 1970 = 1) (EIA, 2005b, Figure 3, p. 5)

to save energy. Businesses retrofitted their buildings with more efficient heating and cooling equipment and installed energy management and control systems. Factories adopted more efficient manufacturing processes and purchased more efficient motors for conveyors, pumps, fans, and compressors. These investments in more efficient technologies were prompted by higher energy prices and by federal and state policies. About one-third of the freeze in energy use during this period is estimated to have been the result of structural changes to the economy including declines in energy-intensive industries and increases in the service sector; two-thirds are estimated to have resulted from increases in energy efficiency (DOE, 1995). The gains in energy productivity achieved during this period represent one of the great economic success stories of this century.

Energy intensity has continued to decline since 1986, but at a slower pace. In 1970, 18.0 thousand Btu of energy were consumed for each dollar of GDP (2000$) (EIA, 2005a, Table 1.5, p. 13). By 1986, the energy intensity indicator had dropped to 12.3, and by 2004 it was at 9.2. If the nation had the same energy intensity today as it did in 1970, U.S. energy demand would be approximately twice what it is today and the nation's energy bill would be approximately $1 billion per day higher (Figure 2.7). As was true in the late 1970s and early 1980s, reductions in energy intensity have resulted from a combination of energy efficiency investments and structural shifts in the economy away from energy-intensive manufacturing and toward service and information-based jobs. Energy efficiency was and remains an attractive option for strengthening the nation's energy system because it offers a "no regrets" approach – investments in energy efficiency save consumers and businesses money while stretching the nation's energy resources, reducing energy imports, and cutting pollution and GHG emissions.

The building sector is the largest consumer of energy in the United States. The nation's 106 million households, 4.6 million commercial buildings, and 15.5 trillion square feet of industrial building floorspace consume approximately 41% of the

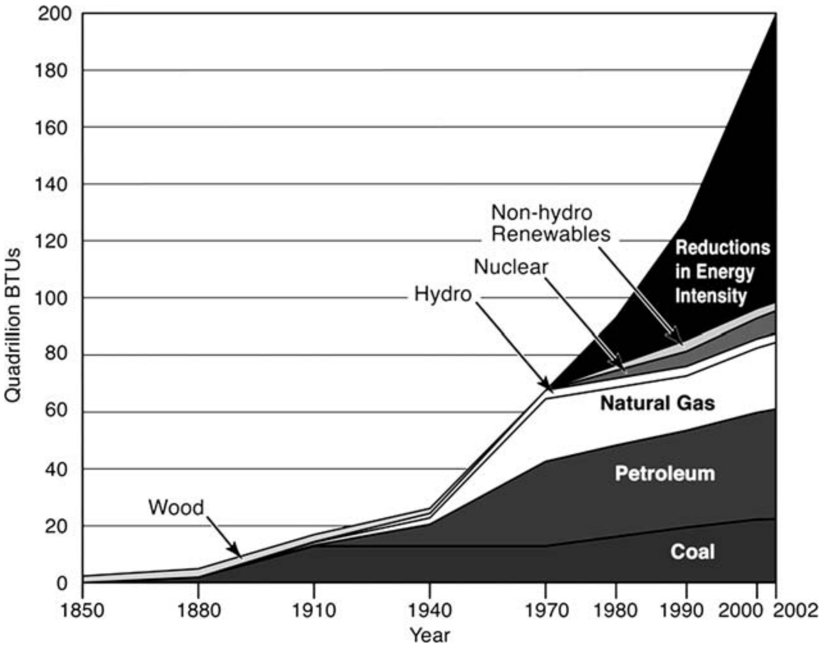

Figure 2.7. Energy saved from reductions in energy intensity: 1970–2002 (Author, Based on Data in Table 1.3, EIA *Annual Energy Review*, 2004)

total U.S. energy budget; most of this energy is consumed by residential buildings (20.9 quads), somewhat less by commercial buildings (17.4 quads), and much less by industrial buildings (2.0 quads) (Brown et al., 2005). Most of the energy used in buildings is consumed by equipment that transforms fuel or electricity into end uses such as heat or air conditioning, light, hot water, information management, and entertainment.

Since 1972, building energy use overall has increased at less than half the rate of growth of the nation's GDP. And since the late 1970s, when detailed energy use data first became available, residential energy use per capita has declined by 27%, residential energy use per household has declined by 37%, and commercial energy use per square foot of commercial building space has declined by 25% (Figure 2.8).

These energy intensities have decreased despite a 50% increase in the size of new homes since 1970 and the growing use of air conditioning, electronic equipment, televisions, and a multitude of "plug loads." Today, central air conditioning exists in 85% of homes in the United States, up from 34% in 1970 (Brown et al., 2005).

A remarkable example of the potential for energy-efficiency improvements is the household refrigerator. Beginning in the mid-1970s, a collaborative effort between government and industry led to significant energy savings without sacrificing size or price. Refrigerators today use 75% less energy than they did in 1970. These technology improvements, in conjunction with the issuance of appliance standards,

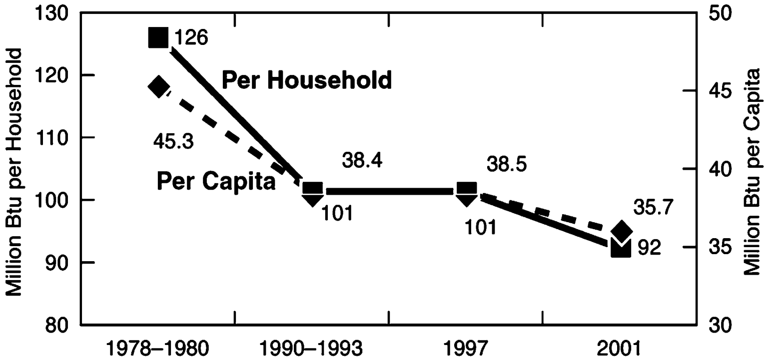

Figure 2.8. Residential energy use per capita and per household (Adapted from Brown et al., 2005, Figure 2, p. 2)

have saved U.S. consumers billions of dollars in energy costs and have reduced the need for new power plant construction (National Research Counicl, 2001). The potential for continued efficiency improvements remains significant, but policies are needed to convert this potential into a reality – as documented by a recent assessment of the benefits of stronger appliance and equipment efficiency standards (Nadel et al., 2006) and by economy-wide engineering estimates of efficiency potentials (Brown et al., 2001).

The National Action Plan for Energy Efficiency (2006), prepared and endorsed by more than 50 organizations and agencies, provides five recommendations for helping states and utilities overcome policy, regulatory, and other barriers that limit investment in energy efficiency:

1. Recognize energy efficiency as a high-priority energy resource;
2. Make a strong, long-term commitment to implement cost-effective energy efficiency as a resource;
3. Broadly communicate the benefits of and opportunities for energy efficiency;
4. Promote sufficient, timely, and stable program funding to deliver energy efficiency where cost-effective; and
5. Modify policies to align utility incentives with the delivery of cost-effective energy efficiency, and modify ratemaking practices to promote energy efficiency investments.

The last recommendation is particularly important to the future of electric end-use efficiency because it addresses the situation in many states where electric utility profits are proportionate to electric sales, resulting in incentives to promote more – not less – electricity use.

In stark contrast to the advances in efficient buildings over the past 30 years, the transportation sector is not experiencing fuel economy improvements. In fact, the consumption of energy for transportation is growing more rapidly than energy use in any other sector and is responsible for the overall growth in energy per capita shown in Figure 2.6. There are many causes of this, including the stagnant fuel economy of vehicles since 1981. Interestingly, the configuration of the built environment has also dictated much of the growth in transportation fuel use. The well-documented post-World War II flight to the suburbs by both households and businesses has created the phenomenon of urban sprawl, with ever-expanding distances to be traversed by commuters, goods, and services (Burchnell et al., 1998). Enabled and encouraged by the popularity of the private automobile, inexpensive gasoline, and an extensive high-speed highway network expansion program, a key characteristic of sprawl has been the emergence of large tracts of essentially single-use land developments. This includes land given over to detached single-family homes, as well as large areas devoted to commercial strip developments, multi-store shopping centers, and office and industrial parks. The resulting separation of trip origins and destinations has translated to a significant increase in not only daily commuting distances, but also in the frequency as well as the length of shopping and personal service trips. Between 1969 and 2001, the average annual vehicle miles traveled per household increased from 12,400 to 21,500 (while average household size fell from 3.2 to 2.6 persons, and the average number of vehicles per household grew from 1.2 to 1.9) (U.S. Department of Transportation, Bureau of Transportation Statistics, 2003).

Over the past decade, many states, planning districts, and metropolitan areas have begun to enact anti-sprawl legislation based on spatially defined growth management strategies. A variety of financial incentives have also been tried, all geared towards more compact and travel-efficient land-use arrangements. The most impressive progress in green building development and smart growth is the product of communities and developers wanting to distinguish themselves as leaders in efficient use of resources and reducing waste in response to local issues of land-use planning, energy supply, air quality, landfill constraints, and water resources. But progress is slow and success is uncertain. The last 30 years has left a legacy of land use that is difficult to change.

To illustrate the need for change, assume that U.S. energy consumption grows 1.5% annually, as has been typical of recent years. At this rate the country will see a 35% increase in energy consumption by 2025 and a 4.1-fold increase by 2100. If the nation could cut its annual energy growth rate in half it would experience only a 16% increase in energy use by 2025 and a 2.0-fold increase by 2100. The result would be a much more viable rate of energy resource expansion.

2.6. THE ENERGY-ENVIRONMENT NEXUS

The U.S. energy enterprise and environmental quality are inextricably linked; thus, the “energy crisis” also has an environmental dimension. For instance, human and ecosystem health has been compromised in many ways by energy pursuits including mountaintop removal during coal mining, cooling water impacts on aquatic life, fish mortality at hydroelectric dams, birds killed by wind turbines, spills from oil tankers, and leaks from oil and gas pipelines. Combined with the impacts of air pollution and greenhouse gas emissions (which are discussed below), these environmental problems resulted in the famous 1997 quote from *The Economist* magazine that "Using energy in today's ways leads to more environmental damage than any other peaceful human activity." As Figure 2.9 shows, fossil fuel use is responsible for a significant percentage of U.S. emissions for a range of pollutants as well as CO_2.

Despite three decades of "clean air" legislation in the United States, air pollution continues to be a serious threat to ecosystem health. Americans are experiencing a rise in respiratory illnesses (especially childhood asthma, which has reached record highs), and visibility continues to degrade due primarily to power plant and vehicle emissions. These problems are particularly severe in regions of the country that rely on coal-based electricity such as much of the Southeast. The Great Smoky Mountains National Park is one case in point where air pollution damage is well documented. Ozone alerts dissuade visitors from hiking and prevent rangers from working several weeks each year. Once breathtaking, visibility in the Smoky Mountains now rarely achieves its "natural" limit of 93 miles. Today, average annual visibility has decreased in winter to an average of 25 miles and in summer to an average of 12 miles.

Electricity production and passenger cars and trucks are the largest sources of air pollution in the United States. The nation has made great progress over the past several decades in reducing emissions from power plants, industry, and transportation. Between 1989 and 2003, emissions from electricity generation and combined heat and power systems decreased dramatically: by 32% for SO_2 (from 17.1 million tons of SO_2 in 1989 to 11.7 million tons in 2003) and by 46% for NO_x (from 9.0 million tons in 1989 to 4.8 million tons in 2003) (EIA, 2005a, Table 12.7a, p. 351). These reductions over time were accomplished by installing pollution control equipment at coal-fired power plants, reducing pollution from industrial processing facilities, reducing the average sulfur content of fuels burned, and using cleaner fuels like natural gas for residential and commercial heat. However, further reductions of SO_2 and other pollutants are still needed to solve the particulate matter and acid rain problems and to improve visibility.

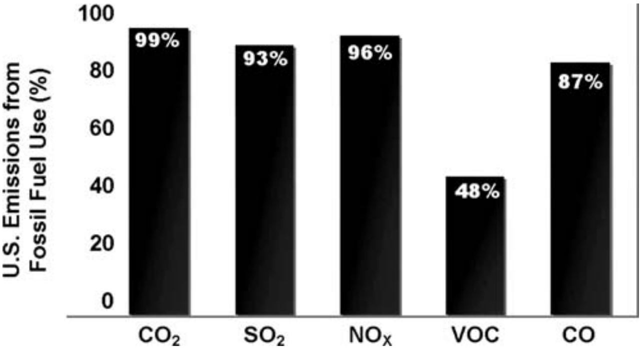

Figure 2.9. Percentage of U.S. emissions from fossil fuel use (Author (Based on data from the following sources: EPA, 2000 and EIA, 2000)

The impact of electric power production on air pollution was vividly documented by the August 14, 2003, Northeast blackout. In addition to shutting off electricity for 50 million people in the United States and Canada, the blackout also shut off the pollution coming from fossil-fired power plants across the Ohio Valley and the Northeast. In effect, the power outage was an inadvertent experiment for gauging the atmosphere's response to the grid's collapse. And the results were impressive. Twenty-four hours after the blackout: SO_2 concentrations dropped 90%; particulate matter fell by 70%; and ozone concentrations were cut in half. These reductions exceeded the expectations of air quality modelers (Marufu et al., 2004).

Beyond air pollution issues, current energy trends will expand emissions of greenhouse gases (GHGs), which appear to be contributing to increased global temperatures, recession of glaciers, and more frequent and extreme weather events such as hurricanes and droughts. To be sure, the scientific understanding of climate change continues to evolve, as do political and business responses to it (Aston and Helm, 2005). Nevertheless, the potential impact of increasing accumulations of carbon dioxide and other GHGs on the Earth's atmosphere is gaining heightened public attention. In 1970 the term "global warming" was largely unknown. The first United Nations Framework Convention on Climate Change wasn't held until 1992, which underscores the recency of this environmental concern. Today the issue is widely covered in the mass media including best selling novels (like Michael Crichton's *State of Fear*) and major Hollywood movie productions (like *The Day After Tomorrow*) fueling the public debate with plots tied to global warming. Vice President Al Gore's movie, *An Inconvenient Truth*, has also kept the global warming debate alive.

While the link between anthropogenic emissions of GHG and global climate change is uncertain, if there is a cause-and-effect relationship, then it is intimately tied to energy consumption. The combustion of fossil fuels is the dominant source of GHG emissions – every quad of energy consumed in the United States, for instance, results in approximately 59 million metric tons of carbon dioxide emissions (EIA, 2005a, Table 12.2, p. 341).

Total U.S. emissions of carbon dioxide from energy consumption have increased significantly: from 4.3 gigatons (i.e., billion metric tons) in 1970[14] to 4.7 in 1980 and 5.9 in 2004 (EIA, 2005a, Table 12.2, p. 341). The EIA forecasts that carbon dioxide emissions from energy use will increase on average by 1.2% annually for the next 25 years resulting in 8.1 gigatons of carbon dioxide emissions in 2025 (EIA, 2006, Table A18, p. 160), almost double the emissions in 1970. Clearly the last 30 years have not provided the low-carbon power and fuels needed for the United States to help stabilize atmospheric concentrations of GHGs, which is the goal set by the United Nations Framework Convention. Stabilization of CO_2 means that global emissions must peak in the decades ahead and then decline indefinitely thereafter. It is estimated that annual CO_2 reductions worldwide by the end of the century need to be as large as 14.5 gigatons (Figure 2.10) (U.S. Climate Change Technology Program, 2006). To illustrate the magnitude of this challenge, consider the examples of a gigaton/year of carbon mitigation provided by Placet,

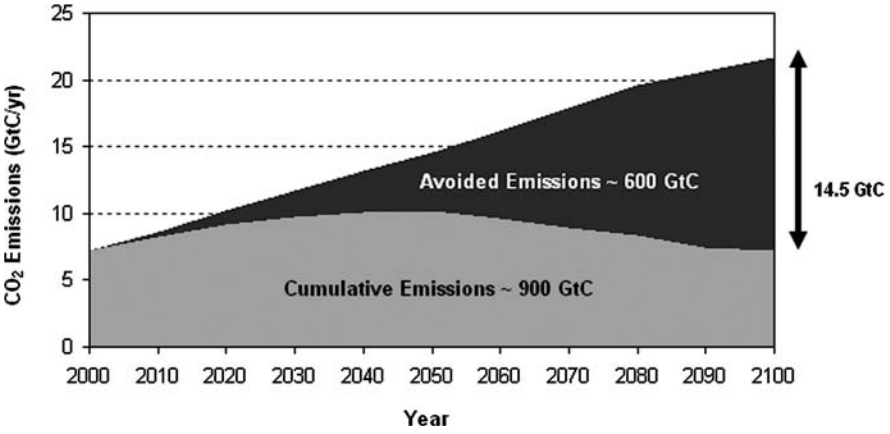

Figure 2.10. Potential scale of CO_2 emissions reductions to stabilize greenhouse gas concentrations: hypothetical unconstrained and reduced-emissions scenarios (Climate Change Technology Program, 2006)

Humphreys, and Mahasenan (2004, p. 202). One gigaton/year of carbon mitigation could be achieved by building 1,000 "zero-emission" 500-MW coal-fired power plants in lieu of coal-fired plants without carbon capture and storage. Alternatively, a gigaton/year could be obtained by deploying one billion new cars at 40 miles per gallon (mpg) instead of 20 mpg. Or a gigaton/year could be achieved by converting a barren area about 30 times the size of Iowa's farmland to new forest.

Such greenhouse gas emission reductions require fundamental changes in the way the world produces and uses energy, and this will require the development of a new generation of energy technologies and approaches. State legislative and regulatory initiatives are beginning to make positive inroads to pollution abatement. For instance, California generates roughly one-fourth of its electricity from efficiently distributed and renewable energy technologies; as a result, it emitted only 12% more GHG emissions in 2002 than in 1990, despite an increase in electricity demand of almost 25%. Unfortunately, such progress remains the exception and not the rule.

To address the century-scale problem of climate change, scientific breakthroughs will be needed to broaden today's options. Currently, the U.S. government spends about $3 billion/year on climate change technology development (Brown et al., 2006); this is less than half the federal energy R&D spent each year in the late 1970s (NCEP, 2004). Given the severity of the nation's energy challenges and the critical need for new technology solutions, energy R&D budgets should be expanding, not shrinking.

In sum, the last 30 years have not seen the market penetration of the low-carbon power and fuels needed to help stabilize atmospheric concentration of greenhouse gases. "Step changes" in our energy system are required so that energy growth can occur without compromising environmental quality.

2.7. ENERGY POLICY PATHWAYS

The magnitude of the nation's energy challenges was discussed during the 4 years of debate preceding the Energy Policy Act (EPAct) of 2005, which the President signed into law in August 2005 (http://www.ne.doe.gov/EPAct2005/hr6_textconfrept.pdf, June 23, 2006). The Act's 1,724 pages of energy legislation created an array of incentives and regulations intended to grow a next generation of power plants, fuels, and infrastructure and prepare the nation to meet its future energy needs. For instance, approximately $3 billion/year of tax subsidies were spent in 2003 and 2004 including renewable energy production tax credits. The 2005 EPAct calls for $14.5 billion of additional tax incentives over the 10-year period covered by the act to bring a variety of new energy supplies and infrastructure on line. Some of the policy provisions are highlighted below.

- **Clean Coal**: Creates an investment tax credit of 20% for integrated gasification combined cycle plants up to $800 million total.
- **Oil & Natural Gas**: The Federal Energy Regulatory Commission (FERC) is granted sole Federal regulatory responsibility for siting of LNG ports; FERC is also named lead agency for interstate natural gas pipeline Federal permitting and the National Environmental Policy Act (NEPA).
- **Nuclear Power**: Creates a production tax credit (PTC) of 1.8 ¢/kWh for the first 6,000 MW of installed new nuclear power capacity.
- **Renewable Energy**: Provides a 2-year extension of the PTC of 1.8 ¢/kWh for renewable facilities brought into production by 2007 and broadens their applicability beyond wind and solar to include incremental hydroelectric power at existing dams, wave, current, tidal, ocean thermal energy, geothermal, open-loop biomass, and landfill gas.
- **Energy Efficiency**: Legislates new efficiency standards on 12 residential and five commercial products and creates tax credits for builders of high efficiency homes, manufacturers of efficient appliances, and taxpayers for home efficiency improvements, and the purchase of new advanced lean burn and hybrid cars and trucks.
- **Electric Reliability**: Requires monitoring stations on the grid for real-time information and provides for mandatory electric reliability standards.

In addition, EPAct 2005 authorizes numerous R&D and demonstration projects to stimulate investment in emerging clean energy technologies. Some of the technologies targeted by the act for such support are enumerated below:

- Over $3 billion for clean coal commercial demonstrations and R&D
- $100M for two demonstration projects for the production of hydrogen through nuclear power
- $100 million annually through 2009 for biodiesel demonstration projects
- Grants to producers to build facilities for ethanol or other renewable fuel
- $2.2 billion through 2009 for R&D on renewable energy technologies.

While the act promotes many of the actions needed to strengthen the nation's energy infrastructure and provide the clean energy required for a sustainable future, much still remains to be done. For instance, funds need to be appropriated to conduct the R&D and demonstration programs authorized in EPAct 2005. Without such appropriations, it is doubtful that capital markets, industry, business, and consumers will be motivated to achieve all of the act's goals. In addition, climate policies are needed to address greenhouse gas emissions, and CAFE standards need to be tightened to improve the fuel economy of the nation's fleet. Many of these additional policies have been enumerated by the National Commission on Energy Policy (NCEP, 2004).

The NCEP was formed in 2002 to develop a revenue-neutral package of policies "designed to ensure affordable and reliable energy for the 21st century while responding to growing concerns about the nation's energy security and the risks of global climate change. The $10 million effort was funded by the Hewlett Foundation in partnership with The Pew Charitable Trusts, John D. and Catherine T. MacArthur Foundation, David and Lucile Packard Foundation, and the Energy Foundation. The bipartisan Commission of 16 members represents diverse expertise and affiliations.

During its first three years in operation, the Commission met a dozen times; sponsored over 35 independent research analyses, and wrote *Ending the Energy Stalemate* (www.energycommission.org, June 23, 2006). Some of the key policy recommendations that were *not* implemented in the 2005 EPAct are highlighted in Box 2.1. The Commission's report also documents the significant impact that such policies could have in moving the nation toward a sustainable energy future. For instance, the Commission's economic analysis projects that the contribution of non-hydro renewable electricity resources could grow to as much as 10% of total generation by 2020 as a result of the proposed greenhouse gas tradable-permits system and increased R&D funding, compared with the EIA forecast of 3% by 2020 (NCEP, 2004, p. 62). The NCEP policy recommendations shown in Box 2.1 illustrate the types of government actions needed to meet the nation's energy challenges.

Box 2.1. Selected Policy Recommendations of The National Commission on Energy Policy (NCEP, 2004)

Oil Security

- Increase and diversify world oil production and strengthen the global network of strategic reserves.
- Significantly strengthen federal fuel economy standards for cars and light trucks while also reforming the CAFE program.
- Provide manufacturer and consumer incentives to promote domestic production and increased use of highly efficient advanced diesel and hybrid-electric vehicles.

(Continued)

Box 2.1. *(Continued)*

Energy Supply

- Adopt effective public incentives for the construction of an Alaska natural gas pipeline.
- Pursue R&D to develop technologies for tapping unconventional natural gas supplies, like methane hydrates.
- Extend the federal renewable energy production tax credit through 2009.

Energy Infrastructure

- Proceed with all deliberate speed to complete DOE’s license application for operating the Yucca Mountain geologic repository and make available all needed resources to complete a rigorous and timely review of that application.
- Address obstacles to the siting and construction of infrastructure to support increased imports of liquefied natural gas (LNG).
- Support ongoing efforts by FERC to promote market-based approaches to integrating intermittent resources into the interstate grid system.

End-Use Efficiency

- Integrate improvements in efficiency standards with targeted technology incentives, R&D, consumer information and programs sponsored by electric and gas utilities.
- Facilitate improved building code compliance.
- Pursue further efficiency opportunities in the industrial and building sector.

Climate Change

- Adopt a mandatory, economy-wide, tradable-permits system for limiting greenhouse gas emissions, with a safety valve designed to cap costs.
- Provide support for the commercial-scale demonstration of geologic carbon storage at a variety of sites.

R&D

- Double annual direct federal expenditures on energy R&D over the period 2005–2010.

2.8. CONCLUSIONS

The past 30 years have seen a significant shift in the fuels and technologies used to produce and consume energy. Some of these changes have strengthened the country's energy system, especially the marked improvement in the efficiency of energy use in buildings and industry and the diversity of fuels now used to produce electricity. Other changes have increased U.S. energy vulnerabilities, including the surge in imported fuels and the lack of investment in new transmission lines. Increasingly, Americans are demanding more energy while at the same time opposing new energy supply and infrastructure projects because they lack an understanding that such changes are necessary to meet their consumption requirements.

Based on the trends noted in this paper, the nation's energy system is as stressed today as it was in the early1970s. Over the past 30 years the United States has become increasingly vulnerable to economic, environmental, political, and military threats because of its growing fuel consumption, lack of transportation fuel diversity, and a challenged energy infrastructure. The myth that this energy crisis is exaggerated, fabricated, or simply a cover-up is counter-productive. Portraying the energy crisis as "hype" thwarts mobilization of the sizeable resources and political will needed to successfully tackle the real and significant energy challenges facing the nation and the world.

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NOTES

[1] This quote is from the CBS News story on September 17, 2002, called "California Energy Crisis A Sham," (http://www.cbsnews.com/stories/2002/09/17/eveningnews/main522332.shtml, June 23, 2006).

[2] See the following website for a more complete description of the proposed legislation: http://www.kucinich.us/floor_speeches/env_excess_profits26apr.php, June 23, 2006.

[3] This story appeared in Salon News A Salon-eye view of the day's news, with investigative reports, analysis and interviews with newsmakers, at http://archive.salon.com/politics/feature/2001/05/17/energy_plan/, June 23, 2006.

[4] Dan Ackman's, May 8, 2001, http://archive.salon.com/politics/feature/2001/05/08/energy/, June 23, 2006.

[5] http://www.time.com/time/nation/article/0,8599,103558,00.html

[6] In the "Chevron Will You Join Us" on-line debate on energy issues, the dialogue on high altitude wind kites can be found at: http://www.willyoujoinus.com/discussion/comment.aspx?pid=5434, June 23, 2006.

[7] Additional information on solar terrestrial and space power generation can be found at: http://www.climatetechnology.gov/stratplan/comments/Hoffert-3.pdf

[8] This and other quotes appear in "Top Of The News: There Is No Energy Crisis," Dan Ackman, Forbes.com, May, 2001, http://www.forbes.com/2001/05/02/0502nocrisis.html, June 23, 2006.

[9] See the discussion of methane hydrates at: http://www.ornl.gov/info/reporter/no16/methane.htm, June 23, 2006.

[10] In 2004, 40.7 quads of energy were consumed to produce a net generation of electricity of 13.5 quads (EIA, 2005a, p. 223).

[11] Transmission and distribution losses in 2004 amounted to a 9% loss of net electricity (EIA, 2005a, p. 223).

[12] More information on the "Oil Shockwave – An Oil Crisis Executive Simulation" can be found at: http://www.energycommission.org/site/page.php?report=8, June 23, 2006.

[13] Activities by the Federal Energy Regulatory Commission (FERC) to implement the Energy Policy Act are described at: http://www.ferc.gov/legal/maj-ord-reg/fed-sta/ene-pol-act.asp, June 23, 2006.

[14] The Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory is the source for the estimate of U.S. carbon emissions in 1970 (http://cdiac.esd.ornl.gov/trends/emis_mon/stateemis/graphics/usacemissions.jpg, June 23, 2006). The Energy Information Administration's estimates begin with 1980.

REFERENCES

Action Plan Leadership Group: 2005, *National Action Plan for Energy Efficiency*, [online] http://www.epa.gov/cleanenergy/actionplan/leadership.htm, accessed September 3, 2006.

Aston, A. and Helm, B.: 2005, "Top Green Companies: The Race Against Climate Change; How top companies are reducing emissions of $C0_2$ and other greenhouse gases," *BusinessWeek* 12 December, p. 58.

Brown, M.A.: 2004, "Obstacles to Energy Efficiency," *Encyclopedia of Energy*, Volume 4, pp. 465–475.

Brown, M.A., Antes, M., Franchuk, C., Koske, B.H., Michaels, G., and Pellegrino, J.: 2006, *Results of the Technical Review of the Climate Change Technology Program's R&D Portfolio*, Oak Ridge National Laboratory, Oak Ridge, TN, [online] http://www.ornl.gov/sci/eere/communications.htm, accessed June 21, 2006.

Brown, M.A., Southworth, F., and Stovall, T.K.: 2005, *Towards a Climate-Friendly Built Environment*. Pew Center on Global Climate Change, Washington, DC, [online] http://www.pewclimate.org/global-warming-in-depth/all_reports/buildings/index.cfm, accessed June 22, 2006.

Brown, M.S., Levine, M.D., Short, W., and Koomey, J.G.: 2001, "Scenarios for a Clean Energy Future," *Energy Policy* 29 (14), pp. 1179–1196.

Brown, S.: 2003, "How Will the Blackout Shape the Future of T&D," *Utility Automation and Engineering T&D*, Vol. 9, No. 5.

Burchnell, R.W., Shad, N.A., Listokin, D., Phillips, H., Downs, A., Seskin, S., Davis, J.S., Moore, T., Healton, D., and Gall, M.: 1998, *The Costs of Sprawl – Revisited*. TCRP Report 39. Transportation Research Board, National Academy Press, Washington, DC, USA.

Eddison Electric Institute: 2005, *EEI Survey of Transmission Investment: Historical and Planned Capital Expenditures (1999–2008)*, EEI, Washington, DC, [online] http://www.eei.org/industry_issues/energy_infrastructure/transmission, accessed June 22, 2006.

[EIA] Energy Information Administration: 1998, *25th Anniversary of the 1973 Oil Embargo*. DOE/EIA-0624, Washington, DC, [online] http://www.eia.doe.gov/emeu/25opec/anniversary.html, accessed June 21, 2006.

[EIA] Energy Information Administration: 2000, *Emissions of Greenhouse Gases in the United States*. DOE/EIA-0573 (00). EIA, Washington, DC, USA.

[EIA] Energy Information Administration: 2004, *Annual Energy Review 2004*, [online] http://tonto.eia.doe.gov/FTPROOT/multifuel/038404.pdf, accessed July 2006.

[EIA] Energy Information Administration: 2005a, *Annual Energy Review 2004*, DOE/EIA-0384 (2004), Washington, DC, [online] http://www.eia.doe.gov/emeu/aer/, accessed June 21, 2006.

[EIA] Energy Information Administration: 2005b, *Annual Energy Outlook 2005*, DOE/EIA-0383 (2005), Washington, DC, [online] http://www.eia.doe.gov/oiaf/archive.html, accessed June 22, 2006.

[EIA] Energy Information Administration: 2006, *Annual Energy Outlook 2006*, DOE/EIA-0383 (2006), Washington, DC, [online] http://www.eia.doe.gov/oiaf/aeo/, accessed June 21, 2006.

[EPRI] Electric Power Research Institute: 2003, *Electricity Technology Roadmap: Meeting the Critical Challenges of the 21st Century*, EPRI, Palo Alto, CA, USA.

Hadley, S.W., MacDonald, J.M., Ally, M., Tomlinson, J., Simpson, M., and Miller, W.: 2004, *Emerging Energy-Efficient Technologies in Buildings: Technology Characterizations for Energy Modeling*, Prepared for the National Commission on Energy Policy, ORNL/TM-2004/63, Oak Ridge National Laboratory, Oak Ridge, TN, USA.

Hirsh, Richard F.: 1999, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System*, MIT Press, Cambridge, MA, USA.

Hirst, E.: 2004, *U.S. Transmission Capacity: Present Status and Future Prospects*, Consulting in Electric-Industry Restructuring, Bellingham, WA, USA.

Hoffert, M.: 2006, "Embrace the Disruptive," *Technology Review*, July/August, p. 3.

Interlaboratory Working Group on Energy-Efficient and Clean Energy Technologies: 2000, *Scenarios for a Clean Energy Future*, Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory, [online] http://www.ornl.gov/sci/eere/communications.htm, accessed June 21, 2006.

Marufu, L.T., Taubman, B.F., Bloomer, B., Piety, C.A., Doddridge, B.G., Stehr, J.W., Dickerson, R.R.: 2004, "The 2003 North American electrical blackout: An accidental experiment in atmospheric chemistry," *Geophys. Res. Lett.*, 31, L13106, doi:10.1029/2004GL019771.

Morgan, G., Apt, J., and Lave, L.: 2005, *The U.S. Electric Power Sector and Climate Change Mitigation*, Pew Center on Global Climate Change, Washington, DC, USA.

Nadel, S., deLaski, A., Eldridge, M., and Kliesch, J.: 2006, *Leading the Way: Continued Opportunities for New State Appliance and Equipment Efficiency Standards*, Report Number A062, American Council for an Energy Efficient Economy, Washington, DC, USA.

[NCEP] National Commission on Energy Policy: 2004, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges*, [online] http://www.energycommission.org, accessed September 3, 2006.

[NCEP] National Commission on Energy Policy: 2005, *Oil Shockwave: Simulation Report and Summary of Findings*, [online] http://www.rff.org/rff/Events/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=18167, accessed June 21, 2006.

[NCEP] National Commission on Energy Policy: 2006, *Siting Critical Energy Infrastructure: An Overview of Needs and Challenges*, [online] http://www.energycommission.org, accessed September 3, 2006.

National Energy Policy Development Group: 2001, *National Energy Policy*, The U.S. Government Printing Office, Washington, DC, [online] http://www.whitehouse.gov/energy/, accessed June 21, 2006.

National Petroleum Council, Committee on Natural Gas: 2003, *Balancing Natural Gas Policy: Fueling the Demands of a Growing Economy*, Volume 1, *Summary of Findings and Recommendations*, National Petroleum Council, Washington, DC, 118 pp, [online] http://www.npc.org/reports/ng.html, accessed June 21, 2006.

National Research Council: 2001, *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*. National Academy Press, Washington, DC, [online] http://www.nap.edu/books/0309074487/html/, accessed June 21, 2006.

Placet, M., Humphreys, K.K., and Mahasenan, N.M.: 2004, *Climate Change Technology Scenarios: Energy, Emissions and Economic Implications*, Pacific Northwest National Laboratory, Richland, WA, [online] http://www.pnl.gov/energy/climatetechnology.stm, accessed June 21, 2006

Silberglitt, R., Ettedgui, E., and Hove, A.: 2002, *Strengthening the Grid*, RAND Science and Technology Policy Institute Santa Monica, CA, USA.

U.S. Census Bureau: 2004, *Statistical Abstract of the United States: 2003*. U.S. Census Bureau, Washington, DC, USA, p. 9, table 3.

U.S. Climate Change Technology Program: 2006, *Strategic Plan* (Washington, DC: U.S. Department of Energy, DOE/PI-0005, http://www.climatetechnology.gov accessed December 23, 2006.

[DOE] U.S. Department of Energy (DOE): 1995, *Energy Conservation Trends*, DOE/PO-0034, National Renewable Energy Laboratory, Washington, DC, USA.

[DOE] U.S. Department of Energy (DOE): 2002, "Homeland Security: Safeguarding America's Future With Energy Efficiency and Renewable Energy Technologies." *Tenth Annual Report of the State Energy Advisory Board*, U.S. Department of Energy, Washington, DC, [online] http://steab.org/docs/STEAB_Report_2002.pdf, accessed June 21, 2006.

[DOE] U.S. Department of Energy, Energy Efficiency and Renewable Energy (DOE/EE): 2004, *Wind Power Today and Tomorrow: An Overview of the Wind and Hydropower Technologies Program*, U.S. Department of Energy, Office of Policy, Washington, DC, USA.

U.S. Department of Transportation, Bureau of Transportation Statistics: 2003, *NHTS 2001 Highlights Report BTS 03-05*, [online] http://www.bts.gov/publications/highlights_of_the_2001_national_household_travel_survey/, accessed June 21, 2006.

[EPA] U.S. Environmental Protection Agency: 2000, *National Air Pollutant Emissions Trends Report, 1998*, EPA-454/R-00-0002-March 2000. EPA, Washington, DC, USA.

Wilke, John R. and Cummins, Chip: 2006. "U.S. Accuses BP of Manipulating Price of Propane," *Wall Street Journal*, June 29, p. 1.

Worrell, E., Price, L., and Galitsky, C.: 2004, *Emerging Energy-Efficient Technologies in Industry: Case Studies of Selected Technologies*. LBNL-54828. Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

CHAPTER 3

ENERGY MYTH TWO – THE PUBLIC IS WELL INFORMED ABOUT ENERGY

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3.1. INTRODUCTION

The American public is highly educated. About 25% of Americans have bachelor's degrees (U.S. Census Bureau, 2005a). In some cities like Seattle and San Francisco 51% of the population over the age of 25 have bachelor's degrees (U.S. Census Bureau, 2005b). Additionally, more than 80% of American youth enroll in some form of tertiary education within 5 years of leaving high school (UNESCO, 1998). As an educated nation, we expect people to be well informed about current events and issues facing their communities, especially since information arrives easily into households and businesses via the Internet. Unfortunately, the public is not well informed about a number of issues that face contemporary society like energy and the environment (NEETF and Roper, 2002; NEETF, 2005).

Yet because information is so readily available and accessible via search engines and because we are an educated nation, it is tempting to assume that the public is well-informed. Unfortunately, availability of information does not directly translate into increased public understanding. Other factors such as personal motivation greatly affect individuals' willingness to learn and their awareness and knowledge (Bigge and Hunt, 1980). Furthermore, the sheer quantity of information available to the public is growing so rapidly that no one can be a global scholar. Lyman and Varian published a study *How Much Information? 2000* that concluded:

> The world's total production of information amounts to about 250 megabytes for each man, woman, and child on earth. It is clear that we are all drowning in a sea of information. The challenge is to learn to swim in that sea, rather than drown in it.
>
> (Conclusions Para 1.)

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 51–74

Costa (2006, p. 62) states, “We now have more information than the collective minds in science can understand.” Marshall and Tucker (1992, p. xiii) contend, “The future now belongs to societies that organize themselves for learning.”

The availability of information is important to community-based decision making. Such availability has underpinned the growing popularity of public participation in governmental planning over the last decades.

> The 1990s marked a surge in societal interest in planning and building livable communities and a growing commitment on the part of the federal government to provide the support and information that communities need for sustainable development. At the local, state, and federal levels, efforts were geared toward the inclusion in the decision-making process of all people who live and work in these communities. Further, citizen participation was encouraged from start to finish in the complex process of making decisions that affect the quality of life in communities.
>
> (National Research Council, 2002, pp. 2–3)

An informed public is vital to such processes, especially since community leaders appear to have no greater environmental literacy than the general public (NEETF, 2005). Unfortunately, related to the topic of energy the public overrates its knowledge (NEETF and Roper, 2002).

Within this context of an educated public, let’s examine the energy knowledge of the general population and the things that influence the environmental learning and behaviors of community members.

3.1.1 Background Information

In 2001, the National Environmental Education and Training Foundation (NEETF) commissioned Roper ASW, a global market research and consulting firm known for its telephone and online surveys, to carry out a nationwide telephone survey concerning energy use, conservation, and education. The results of the survey were published in *American’s Low “Energy IQ:” A Risk to Our Energy Future – Why America Needs a Refresher Course on Energy*. The report concluded that, “America gets a failing grade on energy knowledge.” (NEETF and Roper, 2002, p. ii) Furthermore, the report stated, “Most Americans overestimate their energy knowledge.” (p. 7). The report painted a grim picture: Americans in 2001 were uninformed about energy and they were not cognizant of this lack of knowledge.

However, a combination of recent events – rolling blackouts in California with soaring prices for electricity, the ongoing war in Iraq, Hurricane Katrina, and rising prices at the gasoline pump – have made U.S. citizens more aware of the source and cost of energy and U.S. energy policy. Today, most Americans know that energy in the United States comes principally from fossil fuels and that we are dependent on foreign oil from politically unstable regions of the world. Suddenly fuel-efficient cars, Corporate Average Fuel Economy (CAFE) standards, and conservation have more meaning to the public.

This chapter looks generally at the awareness, knowledge and attitudes of U.S. citizens related to several aspects of energy. First, the chapter explores the results of a 2001 nationwide survey of energy-related knowledge. The average number of correct answers for the knowledge section of 10 questions was 4.1 – a failing grade. Americans appeared to know little about where their electricity comes from or that the fastest most cost-effective way to address U.S. energy needs is through conservation. Next, the chapter explores five myths of environmental and energy education: (1) people understand the environmental consequences of their energy consumption, (2) knowledge and awareness change behaviors, (3) values change behavior, (4) consumers often make poor energy decisions because they are not informed that energy-efficient alternatives exist, and (5) energy education is a K-12 school topic. Through examining these myths, the chapter deals with basic relationships between awareness, knowledge, and values and the environmental behaviors people exhibit, both positive and negative.

3.1.2 A Primer on Environmental Education and Behavior Change

Education is often thought of as an effective tool for improving the world we live in. Education campaigns have been successful worldwide changing the behaviors of humans to improve public health, economic conditions, and human well being. At this point in history, education is perceived as a great hope for creating a more sustainable world (UNESCO, 2005). In the United States, education plays many roles, including creating a more environmentally literate citizenry, especially through environmental education.

The overarching goal of environmental education is:

> To develop a world population that is aware of, and concerned about, the environment and its associated problems, and which has the knowledge, skills, attitudes, motivations and commitment to work individually and collectively toward solutions of current problems and the prevention of new ones.
>
> (UNESCO–UNEP, 1976, pp. 26–27)

This overarching goal was further defined to include five goals. The goals are for social groups and individuals to:

- Acquire an awareness and sensitivity to the total environment and its allied problems.
- Gain a variety of experience in, and acquire a basic understanding of, the environment and its associated problems.
- Acquire a set of values and feeling of concern for the environment and the motivation for actively participating in environmental improvement and protection.
- Acquire the skills for identifying and solving environmental problems.
- Provide an opportunity to be actively involved at all levels in working toward resolution of environmental problems (UNESCO, 1978).

Environmental education (EE) is different than disciplinary-based education (e.g., biology) in that behavior change is a goal. Other disciplines work to transfer and develop awareness, knowledge, and skills; however, EE takes further steps and develops positive attitudes and gives people a chance to participate to ameliorate current environmental problems and prevent additional problems. All five of these goals are embedded in good EE programs. In fact, research has shown that knowledge and behavior alone do not lead to behavior change (Hungerford and Volk, 1990). Similarly, pro-environmental values do not lead directly to environmentally friendly behaviors (Byers, 2000). Environmental education is carried out for people of all ages in both formal and free-choice learning environments – formerly called nonformal and informal education programs, such as museum programs and nature center interpretive programs.

Given that EE involves behavior change let's briefly look at one behavior model that looks at the relationship between intensions and actions. The model is based on Fishbein and Ajzen's work on a theory of reasoned action (Ajzen, 1985), which identifies psychological determinants of volitional behavior. The theory of reasoned action "is based on the assumption that human beings usually behave in a sensible manner; that they take account of available information and implicitly or explicitly consider the implications of their actions" (p. 12). "[T]he theory postulates that a person's *intention* to perform (or not perform) a behavior is the immediate determinant of that action. Barring unforeseen events, people are expected to act in accordance with their intentions" (p. 12). Of course, the intention changes with time; the longer the interval the greater the probability of an unforeseen event changing the intention. The determinants of intentions are both personal and social. The personal factor is the individual's evaluation of performing the action, either positive or negative. The term for this personal factor is "attitude toward the behavior." The social factor is the individual's perception of the social pressures to perform or not perform a behavior, and because it is based on perception it is a "subjective norm." The relative importance of the personal and social factors varies from person to person and with the behavior in question.

Going another step deeper to understand intentions, Fishbein and Ajzen examined attitudes toward a behavior and subjective norms. "Attitude toward a behavior is determined by salient beliefs about that behavior…The attitude toward the behavior is determined by the person's evaluation of the outcomes associated with the behavior and the strength of these associations." In brief, the individual subjective probability that the behavior will produce a desired outcome is central to intention to act. For example, an individual will have a good attitude toward recycling if s/he thinks that by doing so it will reduce the local waste stream, prevent pollution, and decrease tax dollars spent on waste disposal. The term for beliefs that underlie an individual's attitude toward a behavior is "behavior beliefs." In addition, subjective norms are also related to belief, but not personal beliefs. Subjective norms are an individual's belief that others or groups of others think s/he should perform or not perform a behavior. For example, an individual will think recycling is expected of her/him if s/he sees the majority of her/his neighbors putting bins of recyclable materials at the curb for collection. Ajzen (1985) summarized the theory of reasoned action, "Generally speaking, people intend to perform a behavior when they evaluate it positively and when they believe that important others think they should perform it" (p. 12). Ajzen also states that not all behaviors are under volitional control and the lack of skills, time, or opportunity can prevent a behavior in spite of intention to act. For example, a person may want to recycle, but no recycle depository exits in the community.

In a specific look at behavior toward the environment, Hungerford and Volk (1990) suggest that knowledge, personal characteristics, attitudes, and skills affect environmental citizenship. Their work parallels the theory of reasoned behavior in some respects, but is specific to amelioration of environmental problems, which are complex and require skills to analyze the current situation and create and implement solutions.

Understanding a few basics of human behavior and environmental education is helpful in examining the myths presented later in this chapter.

3.2. THE STATUS OF ENERGY KNOWLEDGE

3.2.1 2001: Low Energy IQ

Every year for a decade the NEETF – a private, nonprofit organization chartered by Congress in 1990 – commissioned a survey of U.S. households about the environment. The environmental topic changed each year – water, energy, waste, etc. In 2001 they surveyed energy use, conservation, and education. At that time, gasoline was about $1.50 per gallon (Institute for the Analysis of Global Security, 2006). Americans were in a period of sustained economic growth. Relative to other times gasoline did not seem expensive. Energy for transportation, residential use, and industry was plentiful, except in California where rolling blackouts marked the summer. Energy was neither on the forefront of people's minds nor prominent in the larger political discourse. The majority of Americans were not concerned about the energy security of the nation. Of course energy was a concern to people who studied it and those who understood the environmental consequences of its copious generation and consumption. In this climate, NEETF and Roper carried out the national telephone survey on energy.

By telephone, Roper interviewed 1,503 adults 18 years of age and older nationwide. The interviews were conducted between July and September 2001. The margin of error is "plus or minus two percentage points at the 0.95 confidence level" (NEETF and Roper, 2002, p. 42). Roper asked knowledge-based questions such as:

- How is most electricity in the United States generated?
- Which sector of the U.S. economy consumes the greatest percentage of petroleum?
- What percentage of the world's energy does the U.S. consume?
- Has the average miles per gallon used by vehicles increase or decreased in the last decade? (NEETF and Roper, 2002, pp. 46–47)

Respondents did poorly overall on 10 energy knowledge questions (See Table 3.1). If you consider 64% a failing grade as do many high schools, 89% of Americans failed a basic energy knowledge test.

Respondents answered incorrectly on a variety of energy related questions. Table 3.2 records the tested knowledge base and percent of respondents who answered correctly. (Note: all items were multiple-choice, which decreases the

Table 3.1. Number Correct: Knowledge of Energy

Number correct	Percentage of total sample
9–10	1
8	3
7	8
6	13
5 or fewer	76

Source: Based on NEETF and Roper, 2002, p. 6

Table 3.2. Percentage Answering Energy Knowledge Questions Correctly

Content of question	Percent of respondents answering correctly
Source of most energy usage in average home	66
Percent of oil imported from foreign sources	52
Percentage of world's energy consumer by U.S.	50
Disposal of nuclear waste in the U.S.	47
Fastest and most cost-effective way to address energy needs	39
U.S. industry increased energy demands the most in the past 10 years	38
Fuel used to generate most energy in the U.S.	36
How most electricity in the U.S. is generated	36
Sector of U.S. economy consuming greatest percentage of petroleum	33
Average miles per gallon used by vehicles in past 10 years	17
Average number of correct answers	4.1

Source: Based on NEETF and Roper, 2002, p. 6

difficulty compared to fill-in-the-blank questions.) Correct responses varied from a high of 66% who knew that heating and cooling uses the most energy in the average American home to a low of 17% who knew that the average fuel economy of cars decreased over the previous decade. Unfortunately, in 2001 the majority of respondents did not know the source of electricity used to run American homes and industry. Perhaps, the saddest fact is that only 39% of respondents knew that conservation is the most cost-effective way to address energy needs.

The subtitle of the NEETF-Roper Report is *Why America Needs a Refresher Course on Energy*. Given the low scores of Americans the title is apropos.

The low scores contrast with the amount of knowledge that respondents self-reported (See Table 3.3). Respondents over estimated their knowledge of energy.

This self over estimation of energy knowledge leaves us to ponder which is worse: an uninformed person or one who is uninformed and does not realize it?

To put these low scores in perspective, only 12% of Americans surveyed had a passing grade (> 64%). This was far below the 30%, who had a passing understanding of environmental issues in a previous NEETF – Roper survey. Although the report does not give a reason, it begs the question why is knowledge related to energy lower

Table 3.3. Self-Reported Knowledge of Energy and Mean Number of Correct Answers

Level of self-reported knowledge	Mean number of correct answers
A lot	5
A fair amount	4.2
Only a little/practically nothing	3.5

Source: Based on NEETF and Roper, 2002, p. 7

than general environmental knowledge? The reasons are not readily apparent. Let's look more specifically at the energy knowledge questions in the survey.

When asked, "How is most electricity in the United States generated?" only 36% answered correctly – by burning oil, coal, and wood. Analysis of the percentage of who chose the foils (i.e., wrong answers) is interesting. Thirty-six percent chose hydroelectric power plants as the predominant form of electrical generation followed by 11% for nuclear power, 2% for solar, and 16% admitted they did not know. In 2001, less than 6% of U.S. electricity was generated through hydro (EIA, 2005a). Table 3.4 shows the sources of electrical generation in the United States in 2001.

Hydroelectric generation is much cleaner in terms of air pollution than burning of oil, coal, and wood. Specifically, the average coal-burning electrical generation plant produces the following pollution:

- 3,700,000 tons of carbon dioxide (CO_2),
- 10,000 tons of sulfur dioxide (SO_2),
- 500 tons of small airborne particles,
- 10,200 tons of nitrogen oxide (NO_x),
- 720 tons of carbon monoxide (CO),
- 220 tons of hydrocarbons,
- 170 pounds of mercury,
- 225 pounds of arsenic,
- 114 pounds of lead,
- 4 pounds of cadmium, and other toxic heavy metals, and trace amounts of uranium (Union of Concerned Scientist, 2005).

Table 3.4. U.S. Electrical Generation, 2001

Source	Billion kilowatthours	Percentage
Coal	1,904	51
Petroleum	125	3
Natural gas	639	17
Nuclear	769	21
Hydro	217	6
Other	83	2

Source: Based on Energy Information Administration, 2005b

This release of pollutants into the atmosphere lowers air quality and contributes to global warming, which have large implications for human and environmental health.

Although hydropower is not free of environmental impacts (e.g., interrupting salmon runs and endangering riffle species), it generates very little air pollution. Thus, the implication of 36% of respondents saying that the major source of electricity in the United States is hydro is that many Americans think of electrical generation as being much cleaner than it is.

Americans appeared to be fairly savvy about energy use in the average home: two-thirds recognized that the major use of residential energy goes to heating and cooling rooms. This same level of knowledge, however, was not apparent in the questions about which sector of the U.S. economy consumes the greatest percentage of the nation's petroleum. Although 33% of respondents answered correctly with transportation, 28% responded with industrial sector, 10% the commercial sector, and 9% the residential sector. Twenty-one percent admitted they did not know. The implications for public knowledge of environmental impacts of energy use from transportation are large. It appears that about two-thirds of the public does not understand that much of the smog comes from their use of personal and commercial transportation.

Pollution from the transportation sector is large. Burning gasoline in a single occupancy car produces the following pollutants per passenger mile: 0.51 kilograms of carbon dioxide, 2.57 grams of nonmethane hydrocarbons or reactive organic compounds, 20.36 grams of carbon monoxide, 1.61 grams of nitrogen oxides (NO_x), 0.04 grams of total suspended particulates, and 0.07 grams of sulfur oxides (Gordon, 1991, p. 65). Given that the average American vehicle in 1994 traveled 11,400 miles and got about 21 miles to the gallon, this is a large amount of pollution (EIA, 2002). At that number of miles per year, an average car generates 5,814 kilograms of carbon dioxide every 12 months.

One strategy to counteract the emission of carbon dioxide into the atmosphere and the associated global warming is carbon sequestration, such as tree planting. Although sequestration rates vary by age and species, an average 25-year-old northern pine tree absorbs about 6.4 kilograms of carbon dioxide per year and sequesters the carbon in its trunk, roots, and limbs (Colorado Tree Coalition, 2006; Tufts Climate Initiative, 2006). Sequestering 5,814 kilograms of carbon dioxide produced annually by one driver requires about 910 pine trees.

The reader should realize that the figures immediately above ignore air and other pollution caused by the manufacture of cars and trucks, which is significant. "About 15% of the emissions can be traced to manufacturing the vehicles and maintenance items" (Brower and Leon, 1999, p. 55). In pollution accounting, these emissions are attributed to the manufacturing sector; however, it is easy to see how the transportation sector is responsible for a substantial amount of pollution.

Figure 3.1 shows the impact of the transportation sector on land use, water use, water pollution, air pollution, and greenhouse gas emissions. Transportation has broad environmental impacts that are not readily visible to the public. For

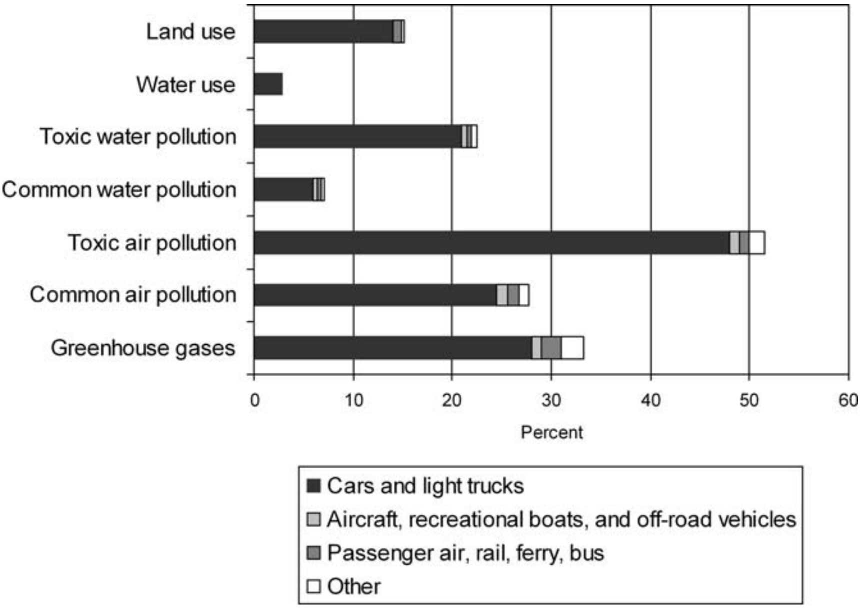

Figure 3.1. Transportation sector: share of total consumer impact. (Adapted from Brower and Leon, 1999)

example, "[A]bout 4 percent of the toxic chemicals released into water come solely from factories manufacturing batteries for household vehicles." (Brower and Leon, 1999, p. 56).

When asked, "Though the U.S. has only 4% of the world's population, what percentage of the world's energy does it consume? Is it...," half of the respondents answered incorrectly or did not know (See Table 3.5).

Those who answered incorrectly or that they do not know, lack knowledge concerning two things. First, and most obvious they do not know how energy consumptive our society is, but additionally they do not know the level of environ-

Table 3.5. U.S. Use of World's Energy Percent of Responses

Percent of energy used by U.S.	Percentage of responses
5%	2
15%	8
20%	19
25% (correct answer)	50
Don't know	21

Source: Based on NEETF and Roper, 2002, p. 4

mental impacts associated with such energy use in the United States. This is a one-two punch in terms of energy and environmental illiteracy.

When asked, "In the past 10 years, has the average miles per gallon of gasoline used by vehicles in the United States increased, remained the same, gone down, or not been tracked?" only 17% of the respondents answered correctly (See Table 3.6).

Unfortunately, many did not realize that the fuel economy of vehicles has dropped after reaching a peak in 1985. The increase in purchasing of large vehicles like sport utility vehicles (SUVs) has lowered the overall efficiency of vehicles on the road (See Chapter 2). About half the vehicles sold in 2005 were "light trucks," which includes SUVs (EPA, 2005). The fact is that recent technological advances in fuel economy have been overshadowed by the American public's desire for bigger, faster, and more powerful vehicles. "EPA estimates that had the new 2005 light-duty vehicle fleet had the same distribution of performance and the same distribution of weight as in 1987, it could have achieved about 24% higher fuel economy" (EPA, 2005, p. V).

The saddest result of the survey was related to conservation. When asked to respond to "Scientists say the fastest and most cost-effective way to address our energy need is to..." only 39% responded correctly with "promote more energy conservation." (See Table 3.7).

Building new power plants and exploration for petroleum are expensive and time-consuming endeavors. In contrast, conservation measures can be undertaken quickly and often inexpensively. Sixteen percent of the respondents perceived that

Table 3.6. Average Miles Per Gallon for Vehicular Use

	Percentage of responses
Increased	62
Remained the same	12
Gone down (correct answer)	17
Not been tracked	3
Don't know	5

Source: Based on NEETF and Roper, 2002, p. 5

Table 3.7. Fastest and Most-Cost Effective Way to Address Energy Needs

	Percentage of responses
Develop all possible domestic sources of oil and gas	16
Build nuclear power plants	14
Develop more hydroelectric power plants	13
Promote more energy conservation	39
Don't know	18

Source: Based on NEETF and Roper, 2002, p. 5

developing domestic oil sources appears to be a solution for solving domestic energy security. In fact, the United States has only 3% of the world's energy reserves. Developing all of them would not come close to meeting domestic energy needs, especially over the long term. The EPA (2005) directly ties energy conservation via fuel economy to national energy security, "Fuel economy is directly related to energy security because light-duty vehicles account for approximately 40% of all U.S. oil consumption, and much of this oil is imported" (p. 4). It is an unfortunate fact that 61% of Americans do not realize that conservation could greatly reduce energy related problems and issues in the United States.

The state of energy-related knowledge of the American public in 2001 was low. In fact it was so low that the NEETF-Roper report concluded, "America's low 'energy IQ' puts our energy future at risk" (2002, p. v).

3.2.2 2005: The Shift in Awareness

Since the NEETF-Roper report was published, the advent of the second Iraq war and the images of sabotaged oil fields and pipelines in the media raised Americans' knowledge of energy and energy issues. Then, Hurricane Katrina devastated the New Orleans damaging the major port on the East Coast capable of receiving large tankers filled with petroleum. Gasoline prices skyrocketed immediately and fuel shortages appeared. Other energy prices (e.g., home heating fuel) also rose. Within a short time prices rose on consumer goods reflecting the higher energy costs to manufacturers. Suddenly, cheap and abundant fuel was no longer available, and correspondingly the energy awareness and knowledge of Americans rose dramatically.

In May 2005, the Yale School of Forestry and Environmental Studies commissioned a study on American attitudes and the environment (YSF and ES, 2005). Among the key findings, 92% of respondents said that dependence on imported oil was a serious problem. As a potential solution, 93% of respondents want the U.S. government to require the automobile industry to manufacture cars that get better gas mileage. The report showed that Americans were very interested in U.S. energy policy and had definite ideas on how to improve it.

In mid-September 2005 – only weeks after Hurricane Katrina hit New Orleans – the Opinion Research Corporation conducted a national opinion survey of Americans for 40MPG.org and the Civil Society Institute. Highlights of the report were:

- 87% thought big oil companies were gouging consumers at the gas pump with high prices.
- 79% would support a tax on the windfall profits of oils companies.
- 81% thought the federal government was not doing enough about dependency on mid-Eastern oil and high energy prices.
- 80% thought automakers should develop hybrid technology for fuel savings. (40MPG.org, 2006).

The apparent public complacency related to energy exhibited in the late 1990s and early years of the new century appears to be gone. The status of energy awareness and knowledge in the United States has changed greatly in the last 5 years as energy has become an economic and political issue. Even with the prominence of energy in the national news, a well-informed public on the multi-faceted topic of energy probably remains a myth.

3.3. ENVIRONMENTAL LITERACY OF AMERICANS

Awareness and knowledge about energy falls under the larger category of environmental literacy.[1] Energy knowledge is only one piece of environmental literacy. Rather than focusing on a piece, let's look at the larger picture of interrelated environmental systems. NEETF describes the acquisition of environmental literacy.

> In the course of a lifetime, an individual will accumulate environmental knowledge from a combination of school, the media, personal reading, family members and friends, outdoor activities, entertainment outlets, and a wide range of other professional and personal experiences. For a few motivated individuals, this can eventually add up to an accomplished environmental literacy. But for most Americans, it falls far short. Most people accumulate a diverse and unconnected smattering of factoids, a few (sometimes incorrect) principles, numerous opinions, and very little real understanding. Research shows that most Americans believe they know more about the environment than they actually do.
>
> (NEETF, 2005, p. v)

Although environmental literacy, like most knowledge, is accumulated over a lifetime, a decade of NEETF-Roper surveys casts doubt concerning the overall accumulation of such knowledge by the adult American public, especially more complex environmental knowledge.

> While the simplest forms of environmental knowledge are widespread, public comprehension of more complex environmental subjects is very limited. The average American adult, regardless of age, income, or level of education, mostly fails to grasp essential aspects of environmental science, important cause/effect relationships, or even basic concepts such as runoff pollution, power generation and fuel use, or water flow patterns.
>
> (NEETF, 2005, p. ix)

The ramifications of a less than environmentally literate public are well described by NEETF.

> We consider low levels of knowledge about the environment as a signal that members of the public will be unprepared for increasing environmental responsibilities in the coming years. As environmental topics and problems become more complex and pervasive, our decades of reliance on trained experts within the private and public sectors to handle our needs are nearing an end. In the future, many leading environmental problems, ranging from water quality to ecosystem management, will require the efforts of more skilled non-experts acting as individuals, through small business, or as community leaders.
>
> (p. ix)

Ten years of NEETF-Roper surveys revealed that, "There is little difference in environmental knowledge levels between the average American and those who sit on governing bodies, town councils, and in corporate board rooms, and whose decisions often have wider ramifications on the environment" (p. ix). This conclusion is disconcerting at best, especially given that the environmental literacy of the average voting citizen is low. Many Americans assume that the knowledge of people in positions of responsibility is greater than their own. In terms of environmental literacy this appears to be an invalid assumption.

The poor state of environmental literacy in the U.S. has its roots in many arenas – incomplete media coverage of environmental issues and topics; formal education curriculums, which do not include new millennium perspectives on environmental issues that face communities across the United States; and lack of self-motivation by the public to be more knowledgeable. The next section of this chapter focuses on common myths associated with environmental knowledge and environmentally responsible behaviors.

3.4. MYTHS OF ENVIRONMENTAL AND ENERGY EDUCATION

In 1976 Harold Hungerford and Ben Peyton published *Teaching Environmental Education*. They listed and explained eight myths of environmental education. Their list included a number of timely topics such as "Don't worry, everything's 'gonna be all right' – the Projected Theory Syndrome." They debunk the educational approach that "environmental evils are and will continue to be amenable to scientific and technological solutions" (p. 6). This chapter deals with five myths related to energy, education, and human behavior. The myths are:

- People understand the environmental consequences of their energy consumption
- Knowledge and awareness change behavior
- Values change behavior
- Consumers often make poor energy decisions because they are not informed that energy-efficient alternatives exist.
- Energy education is a K-12 school topic.

You may ask, "why should we deal with myths?" Myths are like misconceptions, "existing misconception must be eliminated before new concepts can be learned" (Phillips, 1991, p. 21). For you to understand the role of education in public awareness, knowledge, and environmentally responsible behaviors, you need to understand common misconceptions and identify whether or not you hold them. If an individual holds a misconception, it prevents learning new information and concepts. Also, the knowledge that individuals hold misconceptions should effect the design of education programs and instruction. Liggit-Fox (1997) states,

> [W]e assume that giving the 'correct' information will make them abandon their misconception and adopt the new information. We need to understand that students form misconception based on their experiences. As a result, our students do not have any motivation to give up their closely held beliefs because their misconceptions seem to work.
>
> (p. 29)

Discovering misconceptions is difficult and often time consuming (Philips, 1991). Once discovered, educators often share the misconceptions and methods they used to identify them. From reading studies on public opinion, talking to colleagues around the world, and years of personal observation, I identified five myths for discussion in this chapter.

3.4.1 Myth: People Understand the Environmental Consequences of their Energy Consumption

In 1995, The Merck Family Fund commissioned a public opinion survey, which was conducted by the Harwood Group. (The Harwood Group is part of the Harwood Public Institute for Public Innovation a nonprofit, nonpartisan organization that works to improve public life and politics.) The resulting report *Yearning for Balance: Views on Consumption, Materialism and the Environment* captured citizen perspectives on issues of consumption. The report concluded,

> People perceive a connection between the amount we buy and consume and their concerns about environmental damage, but their understanding of the link is somewhat vague and general. People have not thought deeply about the ecological implications of their own lifestyles; yet there is an intuitive sense that our propensity of "more, more, more" is unsustainable.
>
> (p. 2)

The report elaborated,

> but beyond a general sense that we are on the wrong track, public understanding of the link between consumption and the environment remain somewhat fuzzy. More familiar concepts such as *waste, pollution*, and *recycling* are seen as more directly related to environmental problems and solutions.
>
> (p. 4)

In my own work of assessing environmental issues as part of creating the Environmental Literacy and Citizenship Assessment Instrument, I also found that people have a vague sense of cause and effect of common environmental issues. In a simple test, I asked a group of new graduate students with a variety of disciplinary backgrounds to list the cause and effect of three environmental issues on local and global scales. The responses showed that the students could name and describe an environmental issue, but could not link it to a specific cause. For example, they could describe the death of the hemlocks in the Smoky Mountains, but many attribute it to air pollution such as ozone rather than invasion by an exotic insect, the wooly adelgid. Another example is that students listed air pollution as a problem and the cause as industry; however, much of our air pollution is caused by the transportation sector. A colleague at a university in Illinois said her students had similarly inaccurate responses to the same assessment. Weak cognitive linkages between environmental problems and their cause is common in today's society.

Yearning for Balance (Merck Family, 1995) also noted that, "Only a few [respondents] mentioned on their own that consumption is part of the problem." Taking personal responsibility is rarely noted in public opinion surveys related to the environment. Respondents often remark the government is not doing enough or should do more.

In general, Americans are only vaguely aware that their energy consumption has huge negative effects on the environment.

3.4.2 Myth: Knowledge and Awareness Change Behavior

While traveling abroad, I repeatedly hear that if Americans and people in general were aware of the environmental consequences of using technology they would avoid it. As I look at the traffic – cars, taxis, and delivery trucks – clogging the streets on every continent except Antarctica, I wonder how this myth has endured. I usually reply, "Everyone wants a car even though we know that they make our cities dirty, noisy, and crowded." This statement is an over generalization, but it makes the point that there are other personal factors – such as mobility, convenience, and status – that overshadow negative effects on the environment in decision making and behavior related to the environment. Nevertheless, the statement about knowledge and technology use does point to a persistent myth that knowledge and awareness will change behaviors related to the environment.

I often hear "if people only knew…" inferring that knowledge would some how miraculously change behavior. The literature contains a number of theories related to behavior and behavior change. For example, the aforementioned work of Fishbein and Ajzen describes "links from beliefs, through attitudes and intentions to actual behaviors" (Ajzen, 1985, p. 11).

Although we rarely equate advertising techniques to educational efforts, Madison Avenue advertising specialists will tell you more than awareness is needed to entice people to buy their products. So we cannot expect that awareness alone will be the basis for consumer decisions related to energy-efficient technology. Knowing that a low-flow showerhead will conserve both water and energy used to heat the water, does not entice homeowners to install one (McKenzie-Mohr and Smith, 1999). However, through education of customers/homeowners, technicians who were trained in education and marketing were able to get homeowners to commit to installing more energy conservation technology (Scherzer, 1996).

Social marketing recognizes and addresses the complexity of changing human behaviors. Social marketing is "a process for influencing human behavior on a large scale, using marketing principles for the purpose of societal benefit rather than for commercial profit" (Smith, 1999, p. 9). McKenzie-Mohr and Smith (1999) describe techniques for community-based social marketing, which is used to foster more sustainable behaviors related to waste reduction, energy and water conservation, and transportation. Generally, community-based social marketing involves: uncovering barriers and benefits to the desired behavior, building commitment, prompting desirable behavior, modeling and establishing norms, providing incentive to enhance motivation to act, and removing external barriers (McKenzie-Mohr and Smith, 1999). Social marketing has been remarkably successful at promoting a variety of environmentally related behavior through this multiple step process (McKenzie-Mohr and Smith, 2006).

We also know from years as K-12 students that if the teachers expected a specific skill, we had to practice it – awareness was not enough. We learned to read and do math though practicing, not awareness alone. Pre-school teachers frequently use multiple-step instructional techniques for teaching young children. Here is an example teaching nursery-school students (ages 3 to 5) to use the wastebasket.

The teacher tells the student the behavior she wants, she shows them, she watches them do it, and then compliments them on how nice it is that they help her keep the room clean, which she likes so much, and she thinks they like it too. Similar multiple-step instructional techniques are needed with children, youth, and adults to teach or change behaviors. Telling is not enough.

As previously mentioned, environmental education is based on five goals. All five of these are embedded in good environmental education programs. From successful environmental education programs, which employ these five goals, it becomes apparent that to have a citizenry who regularly engages in environmentally responsible behaviors, knowledge alone is insufficient.

Behavior change, of course, also has other dimensions. Related to taking personal responsibility, *Yearning for Balance* (Merck Family, 1995) states, "many people are skeptical of each other's willingness to take action. Lacking a collective sense that we are moving forward together, people sit and wait for someone else to act first" (p. 7). The study showed that many people tend to wait for others to act – the government, big corporations, or their neighbors. Other respondents voice the futility of acting alone – "the individual can't do it" (p. 7). The report concludes that people tend to "resist examining their own lifestyles too closely" (p. 7). So again we see that information alone will not lead to behavior change across society.

The picture of awareness and knowledge leading to environmentally responsible behaviors is not totally bleak; here is the good news. NEETF (2005) reports that environmental knowledge does influence easily implemented behaviors. "Increased environmental knowledge works best for simple, easy information and behaviors such as consumer decisions or saving water and electricity" (NEETF, 2005, p. xi). NEETF also reports that environmentally knowledgeable people are: "10% more likely to save energy in the home, 50% more likely to recycle, 10% more likely to purchase environmentally safe products, and 50% more likely to avoid using chemicals in yard care" (p. xi).

A good example of environmental behavior change was associated with the mid-1970s announcement that chlorofluorocarbons (CFCs) threatened the ozone layer. Americans stopped purchasing aerosol spray cans that used CFCs as a propellant. They switched from spray cans of deodorant and hair spray to pumps and roll-ons. Given that about half the CFC produced at that time went into such cosmetic products, the impact was significant (Brower and Leon, 1999, p. 16). Brower and Leon go on to point out that the change from aerosols had been an easily accomplished and painless life-style change. They state, "We can see that individual consumer action works best when it does not require significant consumer sacrifice" (p. 17). They go on to state that taking environmental responsibility is rarely that painless.

3.4.3 Myth: Values Change Behavior

Listening to the myriad of talk shows on the television and radio and to conversation around me, I get the impression that the general public assumes that if people had different values, we would not be in the condition we are – socially and environmentally. This leads to identifying the misconception that values directly influence or change behavior. But the link between values and behavior change is not that direct, just as the link from intention to behavior as described in the theory of reasoned behavior is not a straight path. First, let's take a look at what Americans value and how that relates to treatment of the environment, including the use of energy.

The *Yearning for Balance* (Merck Family, 1995) survey looked at what participants valued and what they thought society valued. Most participants valued responsibility, family life, and friendship, but thought that society in general valued those things less. Respondents also valued financial security and career success, and felt other Americans did too. Participants were particularly concerned that the next generation focuses too much on buying and consuming things. Furthermore, 95% of survey respondents characterized Americans as materialistic. "Many assert that excessive materialism is at the root of many of our social problems" (p. 4). "People are struggling with deep ambivalence about their own values" (p. 9). Respondents felt a tension between their criticism of society's obsession with material things and their own attempts to keep up with the expanding American Dream. This ambivalence illustrates that values are not sufficient alone to direct behaviors.

John Heenan (2006), a prominent values educator in New Zealand, explains that linking values to behavior in an individual requires linking moral knowing and moral feeling to action (i.e., moral behavior).

Byers (2000) describes a nine stepping-stone process for understanding and changing behaviors. Stepping stones include:

> 1. Clarifying your own motives and interest, 2. identifying stakeholders and stakeholder interests, 3. initiating a dialogue with stakeholders, 4. identifying behaviors that affect the environment, 5. prioritizing and agreeing on critical behaviors to address, 6. learning more about factors that affect critical behaviors, 7. developing a vision for a sustainable future, 8. developing activities to affect factors that influence behaviors; 9. monitoring, evaluating, and managing adaptively.
>
> (p. 9)

Although Byers does not use the word values, they are part of motives and interest. Byers shows that going from holding a value to expressing that value in daily behaviors is a complex series of steps. Changing values alone does not change behavior.

3.4.4 Myth: Consumers Often make Poor Energy Decisions because they are not Informed that Energy-Efficient Alternatives Exist

Brower and Leon (1999) in *The Consumer's Guide to Effective Environmental Choices: Practical Advice from the Union of Concerned Scientists* look at reducing energy use and environmental impacts through consumer choices. They offer sage advice about how to reduce environmental impact though selection and use of major purchases, such as automobiles and homes. The book was a counterpoint to popular books such as *50 Things Kids Can Do to Save the Earth* and others that offered hundreds of tips for daily living to reduce environmental impacts. Brower and Leon recommend focusing on major actions that can reduce consumption and related environmental impacts rather than minding a myriad of behaviors each with tiny environmental impacts. Through analysis of environmental studies or risk assessments they concluded the four major areas of impact of consumer decisions are: air pollution, global warming, habitat alteration, and water pollution. They state that the most harmful consumer activities are:

- cars and light trucks
- meat and poultry
- fruits, vegetables, and grains
- home heating, hot water, and air conditioning
- household appliances and lighting
- home construction
- household water and sewage (p. 50).

They go on to list "Priority Actions for American Consumers" to reduce environmental impacts:

Transportation

1. Choose a place to live that reduces the need to drive.
2. Think twice before purchasing another car.
3. Choose a fuel-efficient, low-polluting car.
4. Set concrete goals for reducing your travel.
5. Whenever practical, walk, bicycle, or take public transportation.

Food

6. Eat less meat.
7. Buy certified organic produce.

Household operations

8. Choose your home carefully.
9. Reduce the environmental costs of heating and hot water.
10. Install efficient lighting and appliances.
11. Choose an electricity supplier offering renewable energy (p. 85).

Additionally, they list high-impact activities that are best avoided: "powerboats, pesticides and fertilizers, gasoline-powered-yard equipment, fireplaces and wood stoves, recreational off-road driving, hazardous cleaners and paints, and products made from endangered or threatened species" (p. 109). They also recommend not worrying or feeling guilty about the environmental impact of smaller decisions, such as buying a set of Legos for your children. They admit that the plastic they are made from does pollute, but that such toys will be used repeatedly and probably passed on, not thrown away.

Brower and Leon explain that the environmental impact of many consumer decisions cannot be blamed on the consumer, because few environmentally sound alternatives exist. They state, "[C]onsumers do not have complete control over what they consume and how much damage it causes" (p. 13). They cite examples of recent history. Prior to deregulation of electrical utilities, consumers had no choice where their power came from – dirty or green sources. Although people were concerned about lead in their environment, they had to wait for oil companies to produce unleaded gasoline. Brower and Leon insightfully state,

> [W]hat needs to change is the choices available to consumers. The key decisions then need to be made at the corporate, institutional, or governmental level rather than among individuals. Americans seeking to reduce the environmental impact of products would often be best served by pressuring their local, state, or national government to adopt policies that make it easy, or even required, for manufacturers and users of products to choose the environmentally sound option.
>
> (p. 13)

Brower and Leon use the example of household appliances, especially refrigerators. In 1983, the federal government set refrigerator efficiency standards for 1993. At that time, no refrigerator on the market met the pending standards. Consumers benefited tremendously from these new regulations, saving about $22 billion in electrical costs in about a decade. Energy efficiency labeling for refrigerators was also required by the federal government. It addressed the problem that consumers would not be able to make informed decisions about how much a new refrigerator would save in terms of energy simply by looking at it. Such labeling was popular with consumers. Through regulation, government was able to accomplish what individual consumers could not do alone.

The U.S. government currently sponsors the ENERGY STAR® program that has made information available about the energy efficiency of 40 product categories from appliances to homes through the ENERGY STAR program.[2]

Brower and Leon summarize their approach, "We therefore should not assume that the decisions of individual consumers cause most environmental damage. Instead we should focus some of our attention on changing organizations rather than individuals" (1999, p. 14).

Other societal barriers to environmentally responsible behavior related to energy consumption currently exist. For example, environmentally sound residential housing options are not available in many communities. Two friends are looking for a "starter home" to buy. They would like an energy-efficient house in a neighborhood in which they could walk to the grocery store, library, and playground. Unfortunately, the new subdivisions near their places of employment have neither sidewalks nor whole-house energy efficiency design. The young couple is frustrated. They concur with Brower and Leon's statement, "Our choices,...are frequently shaped and constrained by circumstances." Often, energy-wise behaviors are thwarted by lack of consumer options, building codes, and city planning, not lack of knowledge.

As a result, Brower and Leon conclude, "Good government policies are needed for action on the personal lifestyle level to succeed" (1999, p. 146).

3.4.5 Myth: Energy Education is a K-12 School Topic

Many of the energy related issues that face the nation now were not part of common dialogue or the K-12 curriculum when the baby boom generation went to school. With the large evolution in the world of energy production and policy in the last decades, being knowledgeable about current energy issues requires more than a K-12 education.

Fortunately, energy is commonly included in the K-12 curriculum in the United States. Commonly, fifth grade science contains a unit on energy as does high school physical science or general science. As we see in this book, energy is as much a social issues as a scientific-technological issue. However, some social studies curriculums ignore energy. I discovered this fact, while I was doing a curriculum analysis for a statewide meeting. I downloaded the state-mandated high-school curriculum from the Internet and then searched it for the word energy. Surprisingly, the word energy appeared in the science curriculum, but not in the social studies curriculum. How is it was possible to teach world history without mentioning energy, especially in the study of the industrial revolution or contemporary society? Nonprofit organizations and state governmental agencies have done a remarkable job supporting energy education in the K-12 schools (e.g., Wisconsin K-12 Energy Education Program, 2003). But in general energy education is not mandated in K-12 education at a level that matches the profound seriousness of the current national energy situation.

The dropout rate in the United States is about one-third of all high school students. The major complaint of those who dropped out is that "classes were not interesting" (Bridgeland et al., 2006, p. 3). From my own recent high school teaching experience, I know that many students do not find the curriculum relevant to their lives. Furthermore, many of my colleagues, who teach in high school, think that the 9–12 curriculum is not serving the students well and needs a major revision. One way to revise and reorganize the curriculum is to include the study of major issues that face our society today. Adolescents of the new millennium are interested in being able to drive to school and are concerned with rising fuel prices. In the large picture, they are interested in energy. Perhaps, school would be more interesting and relevant, if students were allowed to study topics that engage them such as energy and transportation.

Environmental education for children and youth is highly supported by the public. NEETF-Roper surveys revealed,

> 95% of this public supports environmental education in our schools. And most Americans want environmental education to continue into their adult lives. Over 85% agree that government agencies should support environmental education programs. A large majority (80%) believe that private companies should train their employees to help solve environmental problems. People want to understand environmental issues and how they apply to their daily lives.
>
> (NEETF, 2005, p. ii)

As much as the public supports environmental education, it is not enough.

3.4.5.1 Media

We also have to recognize a very large social force in our society that undoes the good done by energy and environmental education in our schools and society at large. The advertising industry spends $620 billion each year making consumer products desirable to buy (Brower and Leon, 1999). North America is the recipient of much of the advertising efforts as the sponsor gets expanded global exposure for free as our movies, magazines, and media are exported around the world (Charles Hopkins, UNESCO Chair, personal communication, February 2006). "Children between the ages of 2 and 18 spend, on average almost 3 hours daily watching television…The number of television-viewing hours increases between ages 8 and 18" (Singer and Singer, 2001, p. xiv). Considering there is a commercial advertisement break about every 7 minutes, American youth are exposed to 360,000 commercial advertisements before graduating from high school (CyberCollege Internet Campus, 2006). In order to give children and youth awareness, knowledge, and skills to understand their constant bombardment by advertisement and a broader understanding of the influence of media in daily life, media literacy is taught in many countries. Brown (2001) reports, "In the United Kingdom as well as in Canada, Australia, Scotland, Spain and elsewhere, media literacy is required as part of the language arts program in grades 7 through 12" (p. 687). Such a curricular modification in the United States would make environmental and energy education lessons more enduring.

The influence of the media on environmental literacy in the United States goes far beyond the impact of advertising. NEETF reports, "[C]hildren get more environmental information (83%) from the media than from any other source. For most adults, the media is the only steady source of environmental information" (2005, p. x). From watching the national evening news on television, I know that the news media regularly presents sound bites of information about the environment. Rarely does the media give us in depth coverage of an environmental issue. This fragmented and incomplete exposure has implications for national environmental literacy. In fact, it may explain the overall low environmental literacy of U.S. citizenry described previously in this chapter.

3.4.5.2 Energy education

The literature is filled with energy education success stories. For example, the California "Kill-a-watt" education program helped achieve a 6–12% reduction in energy usage statewide (NEETF, 2005). Schools that instituted energy education programs in Canada achieved a 6% decrease in utility costs through conservation alone (Dearness Foundation, private communication, May 2002).

The urgency for such programs was succinctly state by NEETF.

> Standing in the way of solving problem is Americans' current lack of knowledge about energy and environmental issues. Without more widespread energy literacy, fuel resources will be less well managed in home, autos, and businesses, and there will be more waste. Importantly, energy illiteracy means continued dependence on imported oil. But with widespread energy literacy we can easily assume an overall reduction in fuel usage. Home and vehicles will be more efficiently run, and we will cope better with our energy-consumptive technological future.
>
> (NEETF and Roper, 2002, p. 36)

3.5. CONCLUDING REMARKS

Despite the fact that Americans are becoming better educated and that energy issues are gaining in prominence, the idea that the public is therefore well informed about the complexities of our energy system and policies in all likelihood remains a myth. More free-choice learning opportunities are needed for the public. Such programs should do more than raise awareness or change values; they need to involve all five goals of environmental education (i.e., raising awareness, building knowledge, developing skills, identifying values, and having the opportunity to participate to utilize new awareness, knowledge, skills, and values). However, we cannot expect a well-informed public to solve energy and environmentally related problems, especially through their consumer and lifestyle choices. Educational efforts need to be balanced with action from government. Even the most well informed people cannot make good consumer choices if no good alternatives exist. Education must be combined with other practices such as enlightened governmental policy to create a more sustainable future.

NOTES

[1] Several definitions of environmental literacy exist in the literature. In general, environmental literacy is a multi-dimensional quality that is gained over a lifetime. Charles Roth did groundbreaking work on the subject defining three levels of environmental literacy – nominal, functional, and operational. Simmons (1994) gathered many frameworks of environmental literacy as background for the National Project for Excellence in Environmental Education. She synthesized the work into a framework of environmental literacy with seven components: affect (e.g., sensitivity to nature at the intrapersonal level), ecological knowledge, socio-political knowledge, knowledge of environmental issues, cognitive skills (e.g., the ability to analyze, synthesize, and evaluate information about environmental issues), additional determinants of responsible behavior (e.g., locus of control and assumption of personal responsibility), and environmentally responsible behaviors (Volk and McBeth, 1998).

[2] "ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy helping us all save money and protect the environment through energy efficient products and practices." (ENERGY STAR, 2006) Products in more than 40 categories, such as appliances, heating and cooling, and office equipment, are eligible to earn the ENERGY STAR label. One of the purposes of the ENERGY STAR program is to provide consumers with easy access to energy-efficiency information (Brown et al., 2004). The ENERGY STAR label assures the customer that the product uses less energy, saves money, and helps protect the environment. Another purpose of the program is to reduce market barriers for energy-efficient technologies. For more information visit http://www.energystar.gov/.

REFERENCES

Ajzen, I.: 1985, "From theory to actions: A theory of planned behavior," in J. Kuhl and J. Beckman (eds) *Action-control: From cognition to behavior*, Springer, Heidleberg, pp. 11–39.

Bigge, M.L. and Hunt, M.P.: 1980, *Psychological Foundations of Education: An introduction to human motivation, development, and learning*, 3rd ed., Harper and Row, New York, NY, USA.

Bridgeland, J.M., Dilulio, J.J., and Morison, K.B.: 2006, *The silent epidemic: Perspective of high school dropouts*, The Gates Foundation, [online] www.gatesfoundation.org/, search for the title, accessed March 12, 2006.

Brower, M. and Leon, L.: 1999, *The consumer's guide to effective environmental choices: Practical advice form the Union of Concerned Scientists*, Three Rivers Press, New York, NY, USA.

Brown, J.S.: 2001, "Media literacy and critical television viewing in education," in D.G. Singer and J. L. Singer (eds) *Handbook of children and the media*, Sage Publications, Inc., Thousand Oaks, CA, USA.

Brown, M.A.: forthcoming 2007, "Myth one: today's energy crisis is 'hype'," in B.K. Sovacool and M. A. Brown (eds) *Energy and American Society: thirteen myths*, Springer Press, The Netherlands.

Brown, M.A., Southworth, F., and Stovall, T.K.: 2005, *Towards a climate-friendly built environment*, Pew Center on Global Climate Change, Arlington, VA, [online] http://www.pewclimate.org/global-warming-in-depth/all_reports/buildings/index.cfm, accessed July 8, 2006.

Byers, B.: 2000, *Understanding and influencing behaviors: A guide*, World Wildlife Fund, Inc., Washington, DC, [online] http://www.worldwildfife.org/bsp/publications/(search Byers), accessed August 4, 2004.

Colorado Tree Coalition: 2006, *Benefit of trees in urban areas*, Colorado Tree Coalition, Fort Collins CO, [online] http://www.coloradotrees.org/benefits.htm#carbon, accessed July 9, 2006.

Costa, Arthur L.: 2006, "Five Themes in a Thought-Full Curriculum," *Thinking skills and creativity* 1(1) (April), 62–66.

Cyber College Internet Campus: 2006, *The Social impact of television, Part 1*, [online] http://www.cybercollege.com/frtv/frtv030.htm, accessed May 23, 2006.

[EIA] Energy Information Administration: 2002, *Transportation Chapter 3. Vehicle-Miles Traveled*, [online] http://www.eia.doe.gov/emeu/rtecs/chapter3.html, accessed May 24, 2006.

[EIA] Energy Information Administration: 2005a, *Electric power annual*, http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html#figes1, accessed May 17, 2006.

[EIA] Energy Information Administration: 2005b, *Energy perspectives*, Figure 8, Table 8.2a Electricity Net Generation, http://www.eia.doe.gov/emeu/aer/ep/ep_frame.html, accessed May 19, 2006.

ENERGY STAR: 2006, "About energy star," [online] http://www.energystar.gov/index.cfm?c=about.ab_index, accessed July 7, 2006.

[EPA] Environmental Protection Agency: 2005, *Light-duty automotive technology and fuel economy trends: 1975 through 2005 – executive summary*, [online] http://www.epa.gov/fueleconomy/fetrends/420s05001.htm, accessed May 23, 2006.

40MPG.org.: 2006, "Big backlash at the gas pump," [online] http://www.resultsforAmerica.org/calendar/files/ 092205_release.pdf, accessed March 20, 2006.

Gordon, D.: 1991, *Steering a new course: Transportation, energy, and the environment*, Island Press, Washington, DC, USA.

Heenan, J.: 2006, "Making sense of values," [online] http://www.teachingvalues.com/valuesense.html, accessed 10 July 2006.

Hungerford, H.R. and Payton, R.B.: 1976, *Teaching environmental education*, J. Weston Walch Publisher, Portland, ME, USA.

Hungerford, H.R. and Volk, T.L.: 1990, "Changing learner behavior through environmental education," *Journal of Environmental Education* 21(3), 8–21.

Institute for the Analysis of Global Security: 2006, "Global comparison of price per gallon gasoline (January 2001)," [online] http://www.iags.org/gaspricetable.htm, accessed March 31, 2006.

Liggitt-Fox, D.: 1997, "Fighting student misconceptions: Three effective strategies," *Science Scope* 20 (February), 28–30.

Lyman, P. and Varian, H.R.: 2000, *How much information? 2000*, [online]http://www2.sims.berkeley.edu/research/projects/how-much-info/summary.html#conclusion, accessed July 13, 2006.

Marshall, R. and Tucker, M.: 1992, *Thinking for a living: Work, skills, and the future of the American Economy*, Basic Books, New York, NY, USA.

McKenzie-Mohr and Associates: 2006, "Fostering Sustainable Behavior," [online] http://www.cbsm.com (click on cases), accessed July 6, 2006.

McKenzie-Mohr, D. and Smith, D.: 1999, *Fostering sustainable behavior: An introduction to community-based social marketing*, New Society Publishers, Gabriola Island, BC.

Merck Family: 1995, *Yearning for balance: Views on consumption, materialism and the environment*, [online] http://www.newdream.org/yearning/yearn_full.html, accessed March 28, 2006.

[NEETF and Roper] National Environmental Education and Training Foundation and Roper ASW.: 2002, *Americans' Low "Energy IQ." A Risk to Our Energy Future: Why America Needs a Refresher Course on Energy*, NEETF, Washington, DC, [online] http://www.neetf.org/roper/roper.html, accessed February 11, 2005.

[NEETF] National Environmental Education and Training Foundation: 2005, “Environmental literacy in America: What 10 years of NEETF/Roper research and related studies say about environmental literacy in the U.S.” NEETF, Washington, DC, [online] http://www.neetf.org/pubs/index.htm, accessed November 1, 2005.

National Research Council: 2002, *Community and quality of life: data needs for informed decision making*, National Academy Press, Washington, DC [online] http://darwin.nap.edu/books/0309082609/html/1.html, accessed July 14, 2006.

Philips, W.C.: 1991, “Earth science misconceptions: You must identify what they are before you can try to correct them,” *The Science Teacher* 58(2), 21–23.

Scherzer, Philip: 1996, “Completing the conservation cycle: Customer education and customer satisfaction: Human dimensions of energy consumption,” *Proceedings ACEEE Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington, DC, pp. 8.171–8.177.

Simmons, D.: 1994, *The NAAEE standards project: Working papers on the development of environmental education standards*, Monograph, NAAEE, Washington, DC, USA.

Singer, D.G. and Singer, J.L.: 2001, *Handbook of children and the media*, Sage Publications, Inc., Thousand Oaks, CA, USA.

Smith, W.: 1999, *Social marketing lite*, Academy for Educational Development, Washington, DC, [online] http://www.aed.org/SocialMarketingandBehaviorChange/(click on Social Marketing Lite), accessed August 4, 2004.

Tufts Climate Initiative: 2006, *Sequestration: How much CO_2 does a tree take up?* [online] http://www.tufts.edu//tie/tci/sequestration.htm, accessed July 26, 2006.

UNESCO: 1978, Ed/MD/49, April, *Final Report of the Intergovernmental Conference on Environmental Education*, Tbilisi, UNESCO, Paris, [online] http://unesdoc.unesco.org/images/0003/000327/032763eo.pdf, accessed May 25, 2006.

UNESCO: 1998, The *World Education Report 1998: Teachers and Teaching in a Changing World*, UNESCO Publishing, Paris.

UNESCO: 2005, *The United Nations Decade of Education for Sustainable Development 2005–2014 international implementation scheme*, UNESCO, Paris, [online] http://unesdoc.unesco.org/images/0014/001403/140372e.pdf accessed July 7, 2006.

UNESCO–UNEP: 1976, “The Belgrade Charter,” *Connect* 1(1), UNESCO, Paris.

Union of Concerned Scientists: 2005, “Environmental impacts of coal power: air pollution, [online] http://www.ucsusa.org/clean_energy/coalvswind/c02c.html, accessed May 17, 2006.

U.S. Census Bureau: 2005a, People: Education. Available online http://factfinder.census.gov/jsp/saff/SAFFInfo.jsp?_pageId=tp5_education, accessed July 13, 2006.

U.S. Census Bureau: 2005b, “Places within United States R1402. Percentage of people 25 years and over who have complete a Bachelor’s Degree: 2004, Universe: Population 25 years and over. Data Set: 2004 American Community Survey,” [online] http://factfinder.census.gov/servlet/GRTTable?_bm=y&-geo_id=01000US&-_box_head_nbr=R1402&-ds_name=ACS_2004_EST_G00_&-redoLog=false &-mt_name=ACS_2004_EST_G00_R1402_US30&-format=US-32 accessed July 2006.

Volk, T.L. and McBeth, W.: 1998, “Environmental literacy in the United States,” in H.R. Hungerford, W.J. Bluhm, T.L. Volk, and J.M. Ramsey (eds) *Essential readings in environmental education*, Stipes Publishing L.L.C., Champaign, IL, USA.

Wisconsin K-12 Energy Education Program: 2003, *A conceptual guide to K-12 energy education in Wisconsin*, University of Wisconsin–Stevens Point, Wisconsin Center for Environmental Education, Stevens Point, WI, USA.

[YSF and ES] Yale University School of Forestry and Environmental Studies: 2005, *Survey on American attitudes on the environment: Key findings*, [online] www.yale.edu/envirocenter/poll2key.prn.pdf, accessed March 20, 2006.

CHAPTER 4

ENERGY MYTH THREE – HIGH LAND REQUIREMENTS AND AN UNFAVORABLE ENERGY BALANCE PRECLUDE BIOMASS ETHANOL FROM PLAYING A LARGE ROLE IN PROVIDING ENERGY SERVICES

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4.1. INTRODUCTION

In debates over whether the United States could transition to a transportation sector run on bio-fuels, it is often said that the country does not possess enough land to simultaneously feed and fuel the nation. This chapter explores the potential sufficiency of biomass resources in the context of large-scale provision of energy services. Only cellulosic biomass is considered here, as this class of biomass feedstocks is generally seen as having the greatest potential for large-scale energy production. Analysis is focused on production of ethanol, a promising liquid fuel, and on studies of the biomass resource sufficiency of the United States. Some reference is also made to the more limited literature aimed at the important question of evaluating the potential of biomass energy on a global scale.

Ultimately, we believe that biomass merits consideration as a large-scale provider of energy services as the world looks for paths by which to realize a sustainable and secure future. Rather than only adding one more point estimate to the already large pool of evaluations in the literature, we also intend that this chapter contribute to understanding the factors that determine biomass resource sufficiency and why different analyses of this question reach such disparate conclusions.

4.2. THE DILEMMA

Different analyses in the literature have drawn strikingly different conclusions with respect to whether there could be enough biomass to make a significant

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contribution to meeting demand for energy services while also honoring important objectives such as food production, preservation of wilderness, and recreation. Indeed, estimates for the future role of biomass in this context range from suggesting that ethanol could be the largest energy source supporting humankind to no expansion relative to the status quo. It may be observed that these estimates do not cluster around a central mean, but rather exhibit a bimodal distribution with most envisioning either a very small or very large role for biomass.

Among studies suggesting a very limited role for biomass in meeting demand for energy services, the research group led by David Pimentel (Goodman and Pimentel, 1979; Pimentel et al., 1981; Pimentel et al., 1984; Giampietro and Pimentel, 1990; Giampietro et al., 1992; Pimentel et al., 1994; Giampietro et al., 1997; Pimentel et al., 2002) as well as former members of the Pimentel group (Ulgiati, 2001; Giampietro and Ulgiati, 2005) has published a series of papers critical of the merit of biomass-based energy production and project little or no expansion in biomass energy use because of large land requirements, environmental impacts such as loss of biodiversity, degradation of soil fertility, large water demand, and social costs such as an increased occupational hazard for those cultivating biomass crops, and very large fractions of the total labor pool being needed for this cultivation. For example, the 1990 study by Giampietro and Pimentel states that the use of biomass energy as a primary fuel in the United States would be impossible while simultaneously maintaining a high standard of living and Giampietro et al. (1997) state that the land area to supply the energy demand of every citizen in the United States using a particular conversion from woody crops to methanol is 2.5 Billion Ha (6.2 billion acres, over three times the land area of the lower 48 states). Giampietro et al., (1997) and Giampietro and Ulgiati (2005) conclude that “Large-scale biofuel production is not an alternative to the current use of oil and is not even advisable option to cover a significant fraction of it.”

Beyond papers of Pimentel and his former students, a number of other researchers have suggested that use of biomass as a large-scale energy use is limited, undesirable, or unlikely. Hoffert et al. (2002) state that the power density of photosynthesis is too low for biofuels to have an impact on greenhouse gas reduction. Kheshgi et al. (2000) report that twice the global land area used for crops would be needed to substitute for all fossil fuels. Cook et al. (1991) claim it would require an equal amount of land as the total farmed in 1988 (130 million hectares) to supply U.S. transportation fuel. Trainer (1995) concludes that large-scale production of liquid fuels from biomass would require production from tree plantations, and that these plantations are unlikely to achieve desired yields, and therefore will not provide biomass production for much liquid fuel. The Energy Information Administration’s “Annual Energy Outlook” for 2006 (EIA, 2006) predicts that renewable energy use will only increase from 5.8% of total consumption in 2004 to 6.7% in 2025... that biomass’s share of the renewable energy sector will remain nearly constant (42% in 2004; 44% in 2025), that ethanol from cellulose will make up only 2% of all ethanol sold in 2030, and finally that ethanol from corn and cellulose will make up only 2.5% of all energy consumed in the transportation sector in 2030.

Huesemann (2004) claims that, "…any substantial increase in biomass harvesting for the purpose of energy generation would deprive other species of their food sources and could cause the collapse of ecosystems worldwide," and cites very large land requirements as prohibitive for biomass energy use. A recent article in the Washington Post (Jordan and Powell, 2006) concluded that because of large land requirement biofuels are "…not a long-term practical solution to our needs for transportation fuels." Avery (2006) recently stated: "To make ethanol a significant U.S. fuel source will require clearing a tremendous amount of forestland and turning it into farms."

While many studies have drawn negative conclusions about the potential of biomass as a large scale energy source, a significant number have also reached positive conclusions. Johannson et al. (1993) project that biomass could be the largest energy source supporting humankind by a factor of two by 2050. Swisher and Wilson (1993) estimate that the practical potential of biomass energy in 2030 is 30% of current total global energy demand. Woods and Hall (1994) estimate that worldwide, 80% of worldwide energy needs could be produced on plantations, with a further 10% produced from residues. Biomass is the largest contributor among sustainable sources in the sustained growth scenario of Kassler (1994), and in the "energy innovations" scenario developed by a consortium of environmental groups (ACEEE, 1997). Also, Leemans et al. (1996) develop a biomass intensive scenario where almost half of total global energy demand in 2100 is met by biomass. A National Research Council Report (2000) projects that biomass will eventually provide over 50% of U.S. fuel production and over 90% of chemical production. Using the system dynamics model GLUE, Yamamoto (1999) predicts that the potential global biomass energy potential in 2100 is 425 EJ/yr (compared to total 2003 global energy demand of about 400 EJ/yr given in Berndes (2003). Lave et al. (2001) recommend that cellulosic ethanol production should be used to replace all gasoline in the U.S. light duty fleet, although they also projected that this would require 300 to 500 million acres of land (which may be compared to 1.8 billion acres in the lower 48 states). Fischer and Schrattenholzer (2001) conclude that there is a very large potential supply of biomass available in 2050 – greater than current total energy demand – and summarize a scenario where 15% of total global energy demand is met by that date. The "Growing Energy" report of the Role of Biomass in America's Energy Future project (Greene et al., 2004) indicates that biofuels could by 2050 be produced at a level corresponding to more than 50% of current U.S. transportation sector energy use, and that aggressive deployment of biofuels in combination with increased vehicle efficiency and smart growth could replace gasoline essentially completely. The "Winning the Oil Endgame" study by Lovins et al. (2004) projects that biobased fuels and products could provide 20% of the ∼ 20 million barrels a day of petroleum product demand in 2025. Similarly, a 2004 report by the "25 x '25" Ag Energy Working Group states that 25 to 30% of U.S. petroleum imports could be displaced by liquid fuels made from agricultural feed stocks, and, further, that 25% of total U.S. energy consumption could be met by the agricultural sector (including on farm wind and solar power generation) by 2025. A joint study undertaken by the DOE and USDA projected that 1.3 billion tons of biomass could be available in the mid 21st century for conversion to transportation fuels, enough to replace one-third of current demand (Perlack, 2005). Finally, Hoogwijk et al. (2005) find that, taking into account the efficiency of converting biomass into fuels as well as the total production capability of abandoned agricultural land, low-productivity land, and "rest land," that current global oil consumption could be replaced several times over by biomass in the years 2050 and 2100.

In addition to studies that explicitly address whether the role of biomass as an energy source could be (or should be) large or small, many others address in various ways the large and increasing scale of humanity's resource consumption and waste generation in comparison to the planetary systems that ultimately support such activity. As one example among many, "footprint" analysis by Wackernagel et al. (2002) indicates that the rate of global resource consumption by humanity surpassed the regenerative capacity of the earth in about 1980 and that about 1.2 earths would be required to support humanity at the start of the new millennium. If one takes into account projected increases in the world to 10 billion and assumes increasing per capita resource consumption for the world's poor majority, several earths are needed to provide for humanity on a sustainable basis. Of the total human footprint, two thirds is represented by activities central to this chapter: energy production and land used for crops. Lester Brown (2004) has referred to humanity "outgrowing the earth" and the increasingly pressing food security challenges that this entails. For biomass to merit serious consideration as a large-scale provider of energy services, a convincing case must be made that it is possible and desirable to incorporate this additional land-requiring activity in a world that will be placing increasing demands on its finite land resources in the absence of expanded biomass energy production.

4.3. PREREQUISITE CONSIDERATIONS

For the biomass resource sufficiency question to be important, two prerequisites must be met: a positive fossil energy displacement ratio, and potential for sustainable fuel production and utilization cycles.

4.3.1 Fossil Fuel Displacement Ratio

The fossil fuel displacement ratio, R, for biomass conversion can be expressed as:

$$R = \frac{\textit{Fossil Fuel Equivalent Displaced}}{\textit{Fossil Fuel Equivalent Invested}} = \frac{F}{A+C} \tag{4.1}$$

where

$A =$ agricultural energy inputs
$C =$ energy inputs for conversion of biomass feedstocks to fuel
$F =$ energy displaced as a result of the exported products of biomass processing.

In the discussion that follows, all of these energy flows are expressed as dimensionless ratios of fossil fuel equivalent energy relative to the low heating value of cellulosic biomass as it enters the conversion process.

For cellulosic biomass, there is consensus in the literature that energy inputs into feedstock production (including planting, cultivation, harvest, storage, and transport) are small. Thus values for A used in all studies known to us (Nonhebel, 2002; Venturi and Venturi, 2003; Kim and Dale, 2004; Lynd and Wang, 2004; ANL, 2005; Farrell et al., 2006), including studies that have reached negative conclusions about the overall energy displacement ratio (Giampietro and Ulgiati, 2005; Pimentel and Patzek, 2005), range from 0.02 to 0.08. Without exception, every detailed design study known to the authors (e.g., Lynd et al., 1991; DOE, 1993; Wooley et al., 1999; Aden et al., 2002; Reith et al., 2002; Greene et al., 2004; Morris, 2005; Farrell et al., 2006) finds that ethanol can be produced from cellulosic feedstocks with all process energy provided by lignin-rich process residues – in other words, zero is an achievable value for the parameter C even for current technology. Estimates for F range from 0.37 to 0.51 for current technology and ≥ 0.7 for mature technology, depending on the configuration.[1]

Returning to Eq. (4.1), even if the upper end value of 0.08 for agricultural inputs (A) is used, the value of R for current technology is $0.37/0.08$ to $0.51/0.08 = 4.6$ to 6.4. For mature technology, still with the maximum value for agricultural inputs, we have $R \approx 9$. Yet higher values of R are obtained if smaller values of A are assumed. It may also be noted that the auxiliary energy input into oil extraction, transport, and refining (beyond the energy in the crude oil delivered to the refinery) is about 13% of the feedstock combustion energy (estimated from the GREET model; ANL, 2005), roughly twice the value for agricultural inputs into producing cellulosic biomass.

In light of these considerations, conversion of cellulosic biomass to fuels (including but not limited to ethanol) and/or power achieves a decidedly positive fossil energy displacement ratio under a broad range of assumptions. Most studies which suggest a fossil fuel displacement ratio ≤ 1 for ethanol production from biomass base their calculations on forms of biomass other than cellulosic feedstocks (e.g., Pimentel et al., 1984; Giampietro and Pimentel, 1990). The recent evaluation of Pimentel and Patzek (2005), which does consider cellulosic biomass, assumes a process in which externally-supplied processing energy (C) is other than zero. In addition, this study also makes no allowance for integration among internal energy flows within the biomass conversion process. Such integration is a universal feature of today's oil refineries (DOE, 2002), and there is every reason to believe that this will be true of tomorrow's biomass refineries as well. While the low energy-yielding biomass conversion process that Pimentel and Patzek imagine is physically possible, these authors present no evidence whatsoever that the much higher energy-yielding processes projected by many others are not possible. In summary, the authors know of no informed difference of opinion with respect to the proposition that the fossil fuel displacement ratio is decidedly favorable for production of ethanol from cellulosic biomass in a well-designed process representative of anticipated industrial practice.

4.3.2 Sustainability

An analysis of the sustainability of cellulosic ethanol production in all its dimensions is beyond the scope of this chapter. In the most comprehensive study of this issue with authors including representatives of environmental advocacy groups, the *Growing Energy* report (Greene et al., 2004) concludes that production of cellulosic ethanol involves no showstoppers and many potential environmental benefits from an environmental perspective. A key desirable environmental attribute of cellulosic ethanol is the potential for near-zero life cycle greenhouse gas emissions, a direct result of the profoundly positive energy displacement ratio (see above). Other important benefits include increased soil carbon and reduced erosion and water pollution for production of perennial cellulosic biomass feedstocks such as switchgrass as compared to conventional row crops. The main environmental concern expressed in the *Growing Energy* report is the possibility of negative urban air quality impacts associated with expanded use of low-level ethanol:gasoline blends. The report concludes, however, that this can be prevented given the will to do so. All things considered, cellulosic ethanol is regarded as one of the most promising potentially sustainable replacements for petroleum-derived transportation fuels (Greene et al., 2004; Lovins et al., 2004). Realizing the substantial environmental and sustainability benefits available from cellulosic ethanol production and utilization will require diligence as for most if not all energy supply options.

With respect to life cycle issues expressed on a per unit basis – e.g. increased soil carbon per acre planted, displaced oil per fossil fuel invested, mile driven, or GJ ethanol – there are abundant indications that cellulosic ethanol scores very well. To make a meaningful difference with respect to large-scale energy supply, it is necessary that these per unit benefits be multiplied by a large number of units. Resource issues associated with large scale production of ethanol, or any other fuel, from cellulosic biomass represent a greater challenge as compared to life cycle issues (Lynd and Wang, 2004).

4.4. PRIORITIZATION OF END-USES

Systematic consideration of the question of biomass resource availability is fostered by a hierarchical prioritization among biomass end-uses. A rational hierarchy can be based on the extent to which various end-uses can uniquely be met by biomass as indicated by the availability of alternative routes other than biomass by which to provide for these end-uses. Such alternatives may either be based on sustainable or non-sustainable resources.

As presented in Table 4.1, this approach suggests that food is the highest priority end-use because we have neither non-sustainable nor sustainable alternatives to biomass. The next highest priority end-use is organic materials (e.g. lumber, fabric, plastics), for which we have non-sustainable alternatives to biomass but no foreseeable sustainable alternatives. In the area of transportation fuels/energy storage, biomass is the only foreseeable sustainable source of fuels that exist in the

Table 4.1. A Hierarchy of Long Term End-Uses for Biomass

End use	Availability of alternatives		Biomass uniquely suited?	Size of demand (relative)
	Non-sustainable	Sustainable		
Food	No	No	Yes	Large
Organic Materials	Yes	No	Yes among sustainable	Small
Transportation Energy Storage Liquid (@ 1 atm)	Yes	No	Unique among sustainable	Large
Non-liquid	Yes	Yes	No	
Electricity	Yes	Yes	No	Large
Heat	Yes	Yes	No	Large

liquid phase at atmospheric pressure. There are, however, sustainable alternatives to biomass that do not involve liquid fuels, such as mobile energy storage in the form of H_2 or batteries. Thus biomass offers unique functionality in the transportation arena but fuels are a lower priority end-use for biomass as compared to organic materials based on the availability of sustainable alternatives. Given that prominent sustainable resources such as wind, solar, ocean/hydro, geothermal, and nuclear energy are uniquely suited to providing power as opposed to food, materials, or transportation energy storage, it is reasonable that power is a lower priority end-use for biomass as compared to these other end-uses. Finally, many alternatives to biomass are available for providing heat, notably including cogeneration, suggesting that heat be ranked as the lowest priority end-use.

Resource demand for organic materials is small relative to demand for energy to be used as transportation fuel, electricity, and heat. Thus in the context of the hierarchy presented in Table 4.1, transportation fuel represents the highest priority biomass end-use for which resource supply is likely to be a substantial issue. It may also be noted that transportation accounts for a larger fraction of oil consumption than all other uses combined in the United States and many other countries.

4.5. RESOURCE SUFFICIENCY

4.5.1 Land Required for Biofuel Production

4.5.1.1 Land requirements – framework and approach

Notwithstanding the considerable controversy surrounding resources sufficiency issues associated with biomass energy, *calculation of the land area required to provide a given amount of mobility via biofuel production is rather simple.* For travel in light duty vehicles, such land requirements will be impacted by the vehicle miles traveled (VMT, equal to the population times the miles driven per person per year), vehicle efficiency (MPG, miles/gal ethanol), conversion process yield ($Y_{P/F}$, gal ethanol/ton biomass), and the productivity of feedstock production

(P, tons biomass/acre/year). In addition, it is appropriate to allow for the possibility that biomass for fuel production may be available by integration of cellulosic biomass coproduction into currently managed lands from which cellulosic biomass is not newly recovered, as discussed in more detail below. The total annual tonnage of cellulosic biomass available by virtue of integration into currently managed lands is denoted I.

In terms of the variables defined in the preceding two paragraphs, the net new land (beyond currently managed lands) required to produce a given level of mobility (NNL, acres) may be found from

$$\text{NNL}_{\text{FP}} = \left\{ \frac{VMT}{MPG \bullet Y_{P/F}} - I \right\} \frac{1}{P} \tag{4.2}$$

The subscript in Eq. (4.2) denotes that constant land requirements for food production are assumed, a constraint that will be relaxed later.

The first term within the parenthesis in Eq. (4.2) is the total tons per year of biomass required to drive a number of miles equal to VMT miles with a fuel economy of MPG and fuel yield $Y_{P/F}$. The second term within the parenthesis is the total tons per year of biomass available from integrating feedstock production into currently managed lands. The difference between these terms is thus the net number of tons per year produced from new land. Multiplication by inverse productivity (years • acres/ton) results in NNL_{FP} with units of acres. It may also be noted that Eq. (4.2) has intuitively-satisfying trends with respect to the impacts of various variables. Thus, the net new land required increases with VMT, but decreases with increasing vehicle efficiency, process yield, integration of fuel production into currently managed lands and agricultural productivity.

We acknowledge the possibility of using aquatic biomass production for energy applications. While potentially important as a strategy to decrease demand for land associated with biomass energy production, current understanding is not sufficiently advanced – to our knowledge at least – to make meaningful quantitative projections for sustainable energy production systems based on aquatic biomass.

Evaluation of whether biomass could be available at scales sufficient to make a substantial contribution to provision of energy services is important today in a strategic sense. However, several decades of aggressive development will likely be required before limits in biomass availability could conceivably be encountered in the United States at any imaginable rate of growth of the biofuel industry. The biomass resource sufficiency question is thus a question about a state of affairs decades hence. Both agriculture and energy have changed dramatically over the last 30 years. Further changes are likely in any case, and even larger changes than we have seen could occur during the coming decades if the world were to become increasingly motivated by sustainability and/or security objectives.

We present below high and low values for each of the variables in Eq. (4.2) for the purpose of illustrating the impact that these values have on calculated land requirements and understanding why different analyses reach such disparate conclusions. The high and low values presented here are intended to be representative of the range used in different analyses of biomass availability. The values presented are not intended to represent the range of physical possibility and we do not wish to imply here any judgement with respect to how appropriate or probable these values are, although some such judgements are offered in Section 4.7.

4.5.1.2 Illustrative high and low values for the variables in Eq. (4.2)

Vehicle miles traveled. Vehicle miles traveled (VMT) per capita have increased by 1.2% per year for the 10 year period (1992–2002) in the United States (U.S. Department of Commerce, 2003), and several studies anticipate the continuation of this trend (e.g., Hu et al., 2000). Clearly, it is possible for both individuals and city planners to make choices that substantially decrease VMT, even if there is little evidence for such choices being made today. Among the more detailed examinations of the potential for reduced VMT in the United States was that of the "Car Talk" Committee (Policy Dialogue Advisory Committee, 1996). This committee projected a possible average annual increase of 1.9% for the baseline BAU projections over a 35 year period, as compared to a 1.3% increase in a "smart growth" scenario featuring a combination of strategies such as increasing vehicle fuel efficiency and reducing vehicle miles traveled. For this analysis, we use the ratio of the values projected by the Car Talk Committee, 33% (1.9% versus 1.3%) as indicative of the potential for VMT reduction on average annually. Based on this, we use a high value of 6.1 trillion miles traveled in cars and light trucks in 2050, corresponding to the baseline used in the Car Talk analysis, and a low value of 4.5 trillion miles traveled based on the Smart Growth Scenario.

Miles per gallon. The miles per gallon of the light duty vehicle fleet in the United States for the year 2000 is 21 MPG (EPA, 2005), and we take no change in mileage as our base-case. Clearly, MPG could improve dramatically through a combination of consumer choice and technological advancement. Several studies point to the potential for the LDV fleet to achieve MPG comparable to today's hybrid vehicles within two to four decades (Weiss et al., 2000; Friedman, 2003; Cooper, 2006). For example, Freidman (2003) states that a fleet of cars and trucks that takes full advantage of hybrid and other advanced vehicle technologies could reach an average fuel economy of 60 MPG while realizing savings to the consumer over the lifetime of the vehicle. Most studies undertaken over the last 5 years assume that the functional characteristics of the vehicle fleet stay constant. If consumers were willing to sacrifice some elements of function (e.g. power, size), yet larger increases would be possible. Even without considering the possibility of future design changes, historical evidence indicates that recently manufactured high efficiency vehicles are well-represented among vehicles that are safest for their occupants, and are disproportionately represented among vehicles safest for occupants of vehicles they collide with (Ross and Wenzel, 2002). In light of these factors, we think it quite reasonable to take a factor of 2.5 as representative of the ratio of high and low vehicle mileage over the long term, resulting in low-high values of 21 and 52.5 MPG, respectively.

Process yield. For a near term process yield, we assume a value of 55 gallons/dry ton biomass (36 gallons gasoline equivalent/dry ton), obtained by using a process design developed by the National Renewable Energy Laboratory (Wooley et al.,1999) with parameter values consistent with those NREL has achieved in its experimental simulation of an integrated bioethanol process. While some other yield estimates for near-term technology are higher than this (e.g. Aden et al., 2002), we take the value of 36 gal gasoline equivalent as our low-end yield for the purpose of this analysis. Detailed analysis carried out in conjunction with the Role of Biomass in America's Energy Future project (*Growing Energy* report [Greene et al., 2004]; publication of updated analysis in preparation) anticipates yields of up to 91 gal of gasoline equivalent per dry ton cellulosic biomass for mature technology featuring high-efficiency ethanol production in combination with generation of Fischer-Tropsch fuels from fermentation residues.

Feedstock coproduction from currently managed lands. Most studies of biomass availability do not consider the possibility of changing land use in response to demand for non-nutritive cellulosic feedstocks. To represent the status quo, therefore, it seems quite reasonable to use a low value of zero for the tons of biomass available from integrating feedstock production into currently managed lands.

Potentially large quantities of cellulosic biomass could be coproduced from land currently managed for purposes other than fuel production. Such strategies include utilization of residues resulting from current practices, including leaves, stalks and husks associated with grain production, bagasse associated with sugar cane processing, forest industry wastes and residues, and waste sludge associated with paper-making. Alternatively, integration of biomass feedstock coproduction into currently managed lands could be accomplished by new crops and cropping systems that make available more biomass while meeting current needs. Examples of this second type of integration include coproducing feed protein and cellulosic biomass from switchgrass planted on land now used to grow soybeans, using new crops bred to produce larger amounts of residues while not sacrificing yields of currently-harvested products (e.g. large biomass soy, [Wu et al., 2004; McMurtrey et al., 2005]), or planting winter cover crops on land currently left bare. A more detailed consideration of options for integrating cellulosic feedstock production into currently managed lands has been initiated and will be reported elsewhere. It may be noted here that such integration, likely including strategies we do not now foresee, would likely arise in response to market forces in the event that a large demand for non-nutritive cellulosic biomass were to emerge in response to development of cost-effective technology for cellulosic ethanol production.

A recent DOE/USDA study projects availability of residual biomass in the United States at over 600 million tons (Perlack et al., 2005). This estimate includes feedstocks that are either unlikely (e.g. manure) or challenging (e.g. softwoods) to convert to ethanol, and also involves substantial quantities of forest biomass that may be difficult to access in an environmentally benign way. At the same time, the DOE/USDA estimates do not consider potentially large increases in biomass availability from currently managed lands due to significant changes in crops and cropping systems motivated by new demand for energy production. For example, an alternative route to producing 600 million tons of cellulosic biomass from currently managed lands would be to coproduce feed protein and biofuel feedstock by growing switchgrass on 60 million of the 74 million acres now used to produce soybeans while achieving a net feedstock productivity of 10 dry tons/acre/year. Other alternatives, and combinations of alternatives, are also possible (see the discussion in the preceding paragraph). In light of these counterbalancing factors, we think it reasonable to use the DOE/USDA study value of 600 million dry tons as our high-end value for feedstock production from currently managed lands.

Productivity of cellulosic biomass production. The last variable appearing in Eq. (4.2), feedstock productivity (*P*, harvested tons/acre*year) is particularly important. At the low end, Pimentel et al. use a productivity of 1.3 tons per acre per year, based on the sustainable productivity of forests in their analysis of the potential of biomass energy (Pimentel et al., 2002).

Estimating a high value for biomass productivity in the context of this analysis is a challenging undertaking at this time. It should be stated at the outset that different productivity values are appropriate for different purposes, and that great care is warranted when comparing data from different studies or projecting into the future. The same crop will, for example, produce markedly different productivities at different sites (e.g., that vary with respect to rainfall, growing season, soil quality). Moreover, different studies make different assumptions about the quality of sites upon which biomass is grown, and a site that is of a given quality for one crop may be of a quite different quality for another crop. In addition, very high productivities have often been reported in trials in which the grower makes an effort to have factors such as water and nutrients be non-limiting. Such best-case productivities are often 2 to 3-fold higher than obtained under economically-constrained field conditions that are likely to be more representative of a national average. At the same time, there is marked potential for productivity improvement due to both development of improved crops through breeding as well as improved agricultural and silvicultural practices. This is particularly so for cellulosic crops, which have received but scant research effort aimed at increasing productivity of non-nutritive harvestable dry matter. Indeed, asymptotic productivity limits have yet to be demonstrated for any major crop, including crops that have benefited from extensive development efforts such as corn (Tiefenthaler et al., 2003). Thus, we have little practical experience upon which to base estimates of asymptotic limits achievable after large development efforts. It may be noted that corn productivity increases attained in recent decades have occurred with somewhat decreasing nitrogen fertilizer levels and hence are not due to increasing chemical inputs (Hallberg, 2001).

In work led by Dr. Samuel McLaughlin appearing in the Growing Energy Report (Greene et al., 2004), much of which is further detailed and supported in a comprehensive review (McLaughlin et al., 2005), current and future productivities are estimated switchgrass. National average productivities (dry tons per acre per year) based on an economic model that tends to favor switchgrass production on marginal lands are 5 currently, 8 in 2025, and 12.5 in 2050. It is noted in the

Growing Energy report that these values could be achieved without using genetically modified plants. The maximum potential yield of switchgrass – based on simulations founded on plausible physics, biochemistry, and physiology of the crop in its normal growing environment – is estimated by McLaughlin et al. (forthcoming) at 21 dry tons/acre/year. The rates of productivity-driven increase projected in the Growing Energy report correspond to those achieved over the last decade for switchgrass in the United States. In general, it is easier to achieve productivity gains at the initial stages of a program aimed at developing a trait not previously targeted as compared to the latter stages of such a program. Thus, maintaining a given rate of productivity increase will likely require a considerably larger effort as the program progresses. At the same time, new tools for plant breeding are available that are expected to foster faster gains. These include marker-assisted breeding, which do not result in GMO plants, as well as development of transgenic plants (McLaughlin and Kszos, 2005).

Switchgrass was chosen as a model herbaceous energy crop for studies in the United States, and has a larger amount of field data than any other. However, there is increasing awareness that many other candidate crops exist and that some of these crops have substantially higher productivity than switchgrass. For example, in the only side-by-side comparison of switchgrass and *Miscanthus* undertaken to date in the United States, *Miscanthus* averaged 16.5 dry tons/acre/year whereas switchgrass averaged 4.6 dry tons/acre/year for three Illinois sites with data taken over 2 years (Heat and Long, personal communication, 2006). The fact that a well-controlled study showed a 3-fold productivity increase relative to the cellulosic energy crop most widely-studied in the United States is indicative of the nascent status of the field. At the best of three sites in the best of 2 years, a yield of 25 dry tons per acre per year was realized, corresponding to a solar collection efficiency of 4.4% based on visible light striking the site year-round (Heat and Long, personal communication, 2006).

Reports and projections of high biomass productivities are not limited to perennial grasses. Sugar cane experts (Frikkie Botha, South Africa Sugar Research Institute; Fernando Reinach, Allelyx and Votorantim New Business) project that breeding and cultivation of cane with the goal of maximizing total biomass yield can likely result in about 25 dry tons of harvestable biomass per acre per year in the relatively near term. Although sugar cane is currently restricted to tropical and near-tropical climates, data for cane is relevant to estimating biomass production potential and investigation of increasing the geographical range of cane cultivation is underway. Megaflora Corp. has measured productivities of 28 dry tons per acre per year from crossing North American Hardwoods with the polonia tree (Ray Allen, personal communication, 2006).

Ceres, a leading plant biotechnology company, has concluded that available information "strongly suggest[s] that over the next decade or so the deployment of modern breeding and biotechnology technologies will result in average energy yields of at least 15 tons per acre, and that these averages can be sustained across a broad range of geographic and environmental conditions, including the approximately 75 million acres of crop and pasture land in the United States that could easily be converted to their cultivation without impacting domestic food production." (Richard Hamilton, personal communication, 2006). Venture capitalist Vinod Khosla estimates that average productivity values in the range of 20–24 tons per acre per year can be realized in 25 years for energy crops such as switchgrass and *Miscanthus* (Khosla, 2006)

We use for this analysis Khosla's value of 24 dry tons per acre per year for our high estimate of future United States national average biomass productivity. Further research involving the productivity of cellulosic crops potentially useful for energy production, including work aimed at both increasing productivity and narrowing the range of productivities that may reasonably be expected, would appear to be a high priority.

4.5.1.3 Cumulative impact of high and low values for the variables in Eq. (4.2)

Section 4.5.1.2 presents high and low values for five important variables impacting the amount of net new land required in addition to that currently used for food production to provide a chosen level of mobility as calculated by Eq. (4.2): vehicle miles traveled, vehicle efficiency, process yield, energy feedstocks available from integrating into other end-uses, and crop productivity. In Table 4.2, the net new land required to meet projected U.S. mobility demand in 2050 is calculated using Eq. (4.2) with either the least efficient values for each of these variables or the most efficient values for each of these variables. For the least efficient scenario, the calculated land requirement is over six billion acres. This is impossible given that the 48 contiguous states comprise about 1.8 billion acres, with roughly 400 million as cropland, nearly 600 million as grassland, pasture, and rangeland, and another

Table 4.2. Net new land required to satisfy light duty vehicle transportation energy demands in 2050 using cellulosic biofuels: comparison of least efficient and most efficient scenarios

Parameter	Least efficient[a]	Most efficient[a]	Units
VMT (2050, LDV)	6.1	4.5	trillion miles/year
MPG (LDV)	21	52.5	mpg
Process yield	36	91	gal gasoline equiv/ton
Feedstock from currently managed lands I	0	600	million tons
Feedstock productivity	1.3	24	ton/acre/year
Required LDV fuel	235	75	Billion gal gasoline equiv
Food production productivity	Considered subsequently		
Meat consumption			
Net new land required (NNL)[b]	6, 147	23	million acres

[a] See text for sources and justification.

[b] Calculated using Eq. (4.2).

30 million protected in the Conservation Reserve Program (CRP) (Lubowski et al., 2006). For the most efficient scenario, the net new land required is a very modest 14 million acres.

Perspectives on evaluating and realizing the potential of biomass for energy supply in light of the dramatic difference between the scenarios presented in Table 4.2 are offered in Section 5.7.

4.5.2 Land Availability for Biofuel Production

4.5.2.1 *Land availability – framework and approach*

The value OF net new land required to provide for a given VMT is logically viewed in the context of the available land (AL, acres). In general, land available for energy production is the gross managed land (exclusive of land devoted to wilderness, parks, recreation, cities and roads) less the land required for higher priority end-uses. In most contexts, the largest use for managed lands that is higher priority than fuel utilization is production of food (Table 4.1). We consider here land requirements relative to dietary requirements for protein and for carbohydrate. Available land in excess of land required for food production (AL, acres) is a function of gross agricultural land (GAL, acres), the number of people fed (N), the dietary consumption per person (D, mass/person/year), the productivity of crops used (P_f, mass/acre/year), and factors reflecting conversion losses, including but not limited to conversion of crops to animal products (f). Available land may be represented in terms of these factors by Eq. (4.3).

$$\text{AL} = \text{GAL} - N\left(\frac{D}{P_f f}\right) \tag{4.3}$$

4.5.2.2 *Food production productivity*

Crop productivity, P_f, plays a pivotal role in determining available land as represented by Eq. (4.3). During the 20th century, the overall nutritional output per unit land increased dramatically in the United States. This is illustrated by Figure 4.1, which shows that harvested cropland stayed essentially constant over the last 100 years although the country's population tripled.

Hoogwijk et al., (2005) have forecast global land availability for biomass energy production through 2100. The analysis by these authors, the most comprehensive of its kind known to us, considers the geographical suitability for biomass energy production and food production, future land requirements for food production, future productivity of cellulosic biomass, land set aside for nature conservation, land consumed by urbanization, and changes in climate and population. Four different scenarios are analyzed as defined by the IPCC (Nakićenović and Swart, 2000), representing a range of population, food trade, meat consumption, the intensity of crop production and management, technology development, and economic prosperity. For all four scenarios, there is a continuous increase in abandoned cropland throughout the period analyzed, indicative of humanity's aggregated

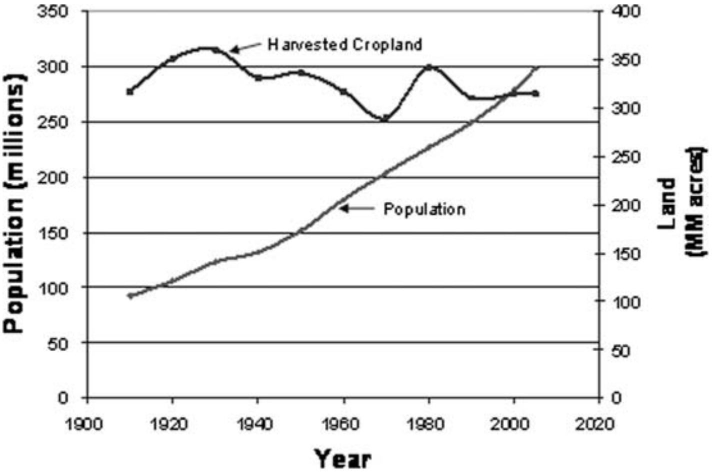

Figure 4.1. Historical data for harvested cropland and population in the U.S. (U.S. Department of Agriculture, 2006; U.S. Census Bureau, 2006)

capacity to produce food exceeding our food requirements over the century just begun. This study predicts that considerable quantities of cellulosic crops could be produced from abandoned U.S. cropland in the 21st century. For example, projected production of cellulosic crops from abandoned US cropland in 2050 for all four scenarios averages 304 EJ/year (~ 180 billion tons/year), with the two scenarios having the highest quantity of abandoned cropland averaging about 400 EJ/year (~ 240 billion tons/year).

As an illustrative example of the impact of the productivity of both food and energy crops, consider the net new land required to produce 100 billion gallons of gasoline-equivalent transportation fuel while also feeding the projected U.S. population in 2050 – 419 million compared to 295 million today. This net new land can be calculated using Eq. (4.4):

$$\text{(4.4)} \qquad \text{NNL} = \frac{G}{Y_{P/F}{}^{*}P} - \text{AL} = \frac{G}{Y_{P/F}{}^{*}P} - \left[\text{GAL} - N\left(\frac{D}{P_f{}^{*}f}\right)\right]$$

where G is the amount of biofuel produced (gallons gasoline equivalent), $\text{Y}_{\text{P/F}}$ is the process conversion process yield (gal gasoline equivalent/ton biomass), and P is the productivity of feedstock production (tons biomass/acre/year).

It may be noted that we have now relaxed the constraint on food production which is implicit in Eq. (4.2). Figure 4.2 presents NNL as a function of the crop productivity multiplier, that is the ratio of productivity in 2050 as compared to that today. The dark grey curve (scenario A) represents the case where energy crop productivity is increased by the multiplier indicated on the X-axis but the productivity of food production does not change from the present. The medium grey curve (scenario B) represents the case where the productivity of food production is increased by the

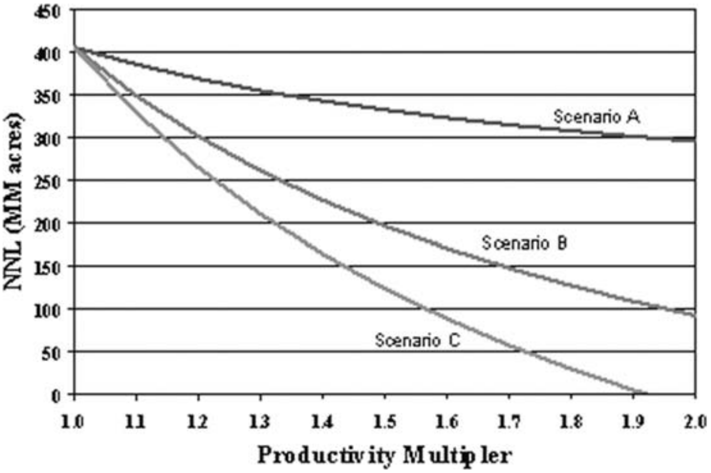

Figure 4.2. Net new land required to produce 100 billion gallons of cellulosic biofuel (gasoline equivalent) in 2050

multiplier indicated on the X-axis but that energy crop productivity does not change from the present. The light grey curve (scenario C) represents the case where both the productivity of food production and energy crop productivity are increased.

It may be observed that all curves involve a large new land requirement of about 400 million acres at a productivity multiplier of one. This corresponds to needing 220 million acres for production of 100 billion gallons of gasoline-equivalent fuel (at an advanced yield of 91 gallons per dry ton and a representative current energy crop productivity of 5 tons per acre/year) together with 185 million new acres to feed a 42% population increase with no change in the land efficiency of food production. The net new land (NNL) required remains high and decrease only modestly if only energy crop productivity is increased (scenario A). By contrast, NNL falls off much more steeply with increasing productivity of food production (scenario B). For increased productivity of both energy crops and food production (scenario C), NNL falls off yet more steeply, although the difference between scenarios B and C is not large.

Inferences that can be made from Figure 4.2 include:

1. Without continued increases in the productivity of food production, projected population increases will result in significant increased land demand for food in the absence of demand for biofuels.
2. Increases in the food productivity of food production beyond that required to keep pace with population growth substantially increase land availability for energy production.
3. As long as more land is used for food production than energy crop production, a given increase in the productivity of food production will have a larger impact on land availability for energy crops as compared to increased productivity of energy crops per se.

4.5.2.3 Diet

Diet has a strong impact on the land required to provide food for a given population. A detailed analysis of the interaction between diet and land availability is outside the scope of this chapter, with only summary perspectives offered here.

As may be seen from the data in Table 4.3, both the amount and type of meat consumed are important variables in this context. Per capita meat consumption nearly doubled in the 20th century in the United States, but could be reduced with no loss – and perhaps gains – in nutrition should consumers choose to do so. Approximately 250 million acres of cropland are devoted to animal feed production (including forage crops) and pasture for meat production, essentially all of which could be used to produce energy crops.[3] In addition, about 350 million acres are devoted to range land, of which some but not all could be used to produce energy crops. Thus, for example, a hypothetical instantaneous 10% reduction in per capita meat consumption, with no changes in the proportions of different meats consumed, would make available a quantity of land in the range of several tens of million acres. A considerably more hypothetical conversion to an entirely vegetarian diet would make available several hundred million acres.

Changes in the relative proportions of various kinds of meat also have large potential impacts on land availability. In 2000, relative consumption of beef, pork, and poultry was as follows: 41% beef, 27% pork, and 32% poultry. Using these values and the data in Table 4.2, a weighted average of 14.3 kg feed per kg edible animal product can be calculated. Per capita meat consumption changed significantly throughout the 20th century however, and there would seem little reason to assume that it will remain constant in the future. Between the mid-1970s and 2000, for example, beef consumption fell by 19%, pork consumption remained essentially constant, and poultry consumption increased by 92%. For a hypothetical future scenario in which beef and pork accounted for 25% of meat consumption and poultry accounted for 50% – which would not seem unreasonable given recent trends – a weighted average of 10.85 kg feed per kg is calculated; a 24% change

Table 4.3. Feed conversion efficiencies for major animal food types

Food type	Feed Conversion	
	(kg feed/kg edible weight)	(kcal feed/kcal edible weight)
Beef	25.0	31.4
Pork	9.4	9.1
Chicken	4.5	7.7
Eggs	4.2	29.5
Fish	2.3	6.6
Milk	0.7	4.3

Notes: Mass conversions from Smil, 2002, assuming feed is corn; corresponding caloric values from USDA National Nutrient Database for Standard Reference; gov/fnic/foodcomp/search/

relative to the situation 2000. Devoting 24% less cropland to animal feed production would make available very roughly 50 million acres.

We reiterate that the values in this section are approximate and only intended to be illustrative, and we acknowledge that many factors come into play that we have not considered: exports, consumption of forage as well as grains in animal feeding, changing feed conversion efficiencies, and no doubt many others. Notwithstanding these significant caveats, we believe that the analysis offered here provides an indication of the magnitude of potential dietary changes on land availability. Particularly given our preliminary results, we would be pleased if our analysis motivated a more detailed examination of this important issue.

4.5.3 A Final Illustrative Example

Consider the land required to meet current levels of light and heavy duty mobility in the United States. For the purpose of a general analysis of large scale biofuel production that could only develop over several decades, we do not constrain the analysis with the different fuel requirements of the current U.S. vehicle fleet. We also assume that food for the U.S. population can continue to be provided from a constant amount of agricultural land, as has been the case for the last century (Figure 4.1).

A stepwise progression from an entirely infeasible land requirement for biofuel production to little or no new land required is illustrated in Figure 4.3.[4] Assuming current values for VMT, process yield, and MPG with no recovery of biomass from land currently managed for other purposes and a representative current energy crop productivity of 5 dry tons/acre/year, over a billion acres are required. Increasing process efficiency to that anticipated in the RBAEF project (Greene et al., 2004), which is still substantially lower than that used in some other studies (Lovins et al., 2004), lowers the requirement to about 400 million acres. Increasing vehicle efficiency could result in a further 2.5-fold decrease to 160 million acres. Substantial further reductions are possible by integrating feedstock production into currently managed lands. For example, recovering 72% of corn stover (which could be accomplished while maintaining constant soil carbon using improved tillage practices, (Sheehan et al., 2004) and realizing a net yield of 5 tons of biomass feedstock per acre per year from converting land now used for soybean production either to switchgrass with protein recovery or to large biomass soybeans, could lower the amount to 40 million acres. Further integration of feedstock production into currently managed lands via a combination of several possible alternatives (Section 4.5.2.2) and/or relatively modest dietary changes (Section 4.5.2.3) could bring the net new land required to essentially zero.

The analysis described in the preceding paragraph and depicted in Figure 4.3 does not include any allowance for increases in the productivity of energy crops, which in our view can reasonably be expected to be 3-fold or more (see section 4.5.1.2). Particularly in light of this observation, it appears that it is physically possible for biomass to provide for future U.S. light and heavy duty vehicle requirements with

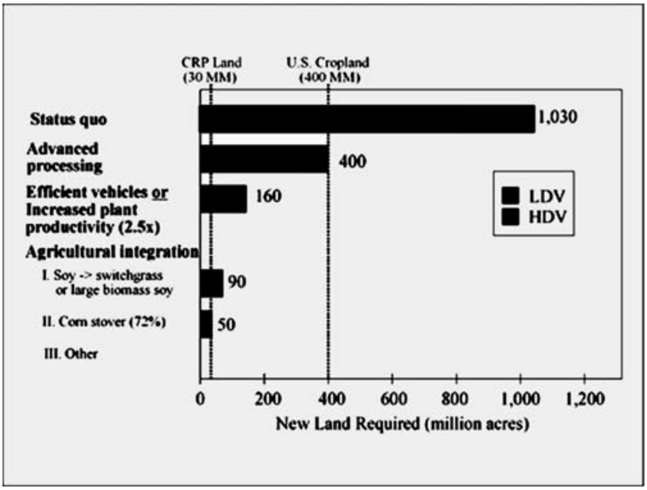

Figure 4.3. New land (i.e. in addition to current cropland) required to meet today's U.S. light and heavy duty vehicle energy demands

no new land required beyond that already devoted to agriculture. Moreover, there is sufficient play in the system that this result could be accomplished via several alternative paths relying on different land-saving factors to different extents.

4.6. UNDERSTANDING THE FACTORS UNDERLYING DIFFERENT EVALUATIONS OF BIOMASS AVAILABILITY FOR ENERGY PRODUCTION

The dramatic difference between the least efficient and most efficient scenarios for biomass energy production, as exemplified by Table 4.1, are consistent with the widely disparate evaluations for the feasibility of biomass making a significant contribution to large-scale energy supply noted at the beginning of this chapter. We observe that this disparity results primarily from different assumed values for input variables to rather simple equations, and that these equations do not differ widely from analyst to analyst. One need look no further than the values for the variables in Eq. (4.2), and especially biomass productivity and the extent of integration of feedstock production into currently managed lands, to understand the basis for differing evaluations of land requirements for biomass energy production.

Given the range of values considered here for the variables in Eq. (4.2) and Table 4.1, believed to be indicative of the range of estimates used by analysts in the field although not physical limits, the relative impact on the calculated net new land requirement is: biomass productivity > feedstock coproduction from currently managed lands > process yields and vehicle efficiency > vehicle miles traveled. In addition, the future productivity of food production would rank high on this list, as illustrated in Figure 4.2 and the accompanying discussion, with a potential impact roughly equal to feedstock production from currently managed lands. These observations are relevant to prioritizing among various topics for research and analysis motivated by the goal of reducing uncertainty associated with projected biomass supply from energy crops. It may be noted that the relative importance of these and other topics is different for objectives other than land availability, for example cost-effectiveness.

As presented in Table 4.3, the factors underlying the very large spread between the high and low estimates for biomass energy land requirements (e.g. in Table 4.2 and Figure 4.3) fall into several categories. Some uncertainty arises with respect to the state-of-affairs in the present or in the near-future without further technological advance. Such "current uncertainty" includes the performance of large-scale production of most cellulosic energy crops, including switchgrass, as well as yet-to-be-built processes for lignocellulose conversion to ethanol.

Differences arising due to different temporal contexts can be dramatic, although they are often not explicit. As one example, distillation energy requirements based on standard practice 30 years ago are substantially higher than based on current practice, and further reductions can be envisioned in the future. The same can be said for biomass productivity. Choosing a consistent temporal context is important, and failure to do so generally results in confusion, which can also result from careless comparison of studies based on studies that are carried out within different temporal contexts. Studies that draw conclusions about future potential based on data applicable to the present, or the past, should be viewed as suspect unless this issue is dealt with explicitly and a convincing argument presented. In addition to parameters that can be expected to become more favorable with respect to large-scale biomass energy production over time (e.g. process yields, crop productivity), it is also important to consider time-dependent changes in parameters that will make such production more challenging (e.g. several factors related to population growth).

Although forecasting the future is necessary to assess potential, it introduces yet further uncertainty. Differences in scope are yet a further factor underlying different assessments of land requirements for biomass energy. For example, if one analysis allows for the possibility of feedstock coproduction from currently managed lands and another does not, they will reach substantially different conclusions about net land requirements.

Finally, and importantly, even analyses with the same temporal context, future technology forecast, and scope can reach substantially different conclusions due to different assumed motivation and/or willingness of people to make changes that are possible both now and in the future. It may be noted that such choices can be driven by either ideological or economic factors, and that this can change over time. For example, in the 1990s with oil at times below $15, motivations with no monetary reward (e.g. reduced contribution to global warming, resource depletion, and demand for foreign oil) were presumably the main factors motivating purchase of an energy-efficient car. Today, with oil prices increased by about 5-fold, there is substantial economic incentive as well, and this could increase if a carbon tax were adopted. Similarly, people choose to reduce meat (or red meat) consumption for a variety of non-monetized reasons today, but this and other changes could be motivated by economic pressures should meat become more expensive.

4.7. OUR ASSESSMENT OF THE BIOMASS SUPPLY ISSUE

We believe that a process yield of 91 gallons gasoline equivalent per ton cellulosic biomass projected by the RBAEF analysis is attainable, representing a 2.6-fold increase relative to a recent NREL design. Although we acknowledge considerable uncertainty in projections of the future productivity of cellulosic biomass production, we believe that energy crop productivity can reasonably be expected to triple relative to a reasonable current estimate of energy crop productivity – about 5 tons/acre*year (McLaughlin et al., in press) – given a substantial effort over a period of a decade or two, with continued increases thereafter. Taken together, increases in process yield and per acre productivity could together, over several decades, result in a roughly 10-fold increase in the per acre fuel yield as compared to current values. In our view, the 1.3 ton per acre per year productivity used in papers authored by David Pimentel and those who cite Pimentel's work is much lower than likely to be achieved if widespread demand for cellulosic energy feedstocks were to materialize.

Given potential for order-of-magnitude increases in per acre fuel yield, the case that biomass can make a large contribution to energy service supply seems very strong to us. For example, 50 million acres devoted to biofuel production at 15 dry tons per acre and 91 gallons of gasoline equivalent per ton would produce 68 billion gallons of gasoline equivalent fuel, which is about half of the current light duty fuel consumption in the United States. We find it likely that 50 million acres of good quality land could be made available for fuel production throughout the next half century and beyond in light of several factors. We observe that there are substantial quantities of land in the United States, notably the Southeast, that are not used for production of row crops but would be well-suited to production of cellulosic feedstocks and have rural economies that would benefit from such production. It may also be noted that 30–50 million acres has been idled by the combination of set-aside programs and the Conservation Reserve Program over the last quarter century in the United States. Production of export crops currently accounts for about 80 million acres. The future productivity of food production is an important variable that is difficult to predict with confidence, although it seems as likely to us that it will exceed the rate of projected population growth through 2050 as it is to fall short of this. Well-founded concern over continued growth in food productivity has been expressed, and this would indeed negatively impact land availability for dedicated production of cellulosic feedstocks. Such concerns are in our view counterbalanced to a substantial degree by the potential for integrating coproduction of cellulosic feedstocks into currently managed lands, which is quite large in our estimation, has been the subject of very little analysis, and will likely be motivated by market forces in the event that a cellulosic biofuels industry emerges.

The analysis presented in the preceding sections makes clear that behavioral changes as well as technical innovation are major factors in determining the energy service supply contribution that could be made from biomass. Vehicle efficiency and dietary choices are particularly important in this context. It may be noted that the direction of current (summer of 2006) trends with respect to both meat consumption (less beef, more poultry) and vehicle efficiency (increased sales of more efficient vehicles motivated by higher fuel prices) are favorable with respect to biomass availability.

If significant continuation of these and other behavioral changes favorable to biomass availability were to occur in combination with innovations in biomass production, conversion technology, and fuel economy: (1) the capacity of biomass energy to make a large energy service supply contribution becomes assured in our view, and (2) it becomes realistic to contemplate biomass providing all U.S. mobility requirements, and (3) it also becomes realistic to contemplate most of the required biomass feedstocks being coproduced from currently managed lands.

Ultimately, questions related to the availability of land for biomass energy production and the feasibility of large-scale provision of energy services are determined as much by world view as by hard physical constraints. If the question is: "In a world motivated to solve sustainability and security challenges, assuming that innovation and change responsive to this objective are possible, could biomass make a large contribution to provision of energy services?" We think that the answer is unequivocally "Yes." On the other hand, biomass can make a much more limited contribution to energy supply in a world based on current or extrapolated realities with respect to important technical and behavioral variables determining biomass requirements and availability. To a substantial degree, the starkly different conclusions reached by different analysts on the biomass supply issue reflect different expectations with respect to the world's willingness or capacity to innovate and change. However, change is our only option if we are to achieve a sustainable and secure future, whether we are talking about biomass or all renewable energy sources.

Rejecting energy service supply options because they require innovation and change decreases the set of alternatives that can make a meaningful contribution markedly, and perhaps to zero. Such rejection also denies the essence of our current situation: that we cannot extrapolate the current unsustainable and insecure present and get to a sustainable and future. The scenarios most conducive to biomass playing a significant energy service supply role involve complimentary combinations of several changes, with the largest contributions made possible by a combination of technical advances and behavioral changes. We suspect that this is not limited to biomass and indeed is true of most if not all paths to a sustainable future. Studies that project a small role for biomass generally change only the source of fuel and leave other variables constant. This, however, amounts to projecting that technologies and behaviors that arose in a world largely unconstrained by energy availability will continue in the future. This is unlikely if one believes that energy sustainability and security challenges will become yet more pressing as we move forward – a proposition for which more support is accumulating daily.

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NOTES

[1] Values cited as energy output per unit feedstock energy on a fossil fuel equivalent basis: $F = (\mathrm{FFE}_{\mathrm{biofuel}} + \mathrm{FFE}_{\mathrm{biopower}})/(E_{\mathrm{feedstock}})$, where $\mathrm{FFE}_{\mathrm{biofuel}}$ = fossil fuel equivalent of biofuel = $E_{\mathrm{biofuel}}/\eta_{\mathrm{petrol.}}$ $\mathrm{E}_{\mathrm{biofuel}}$ = energy content of biofuel; $\eta_{\mathrm{petroleum}}$ = well-to-pump efficiency of petroleum production ≈ 0.85; $E_{\mathrm{feedstock}}$ = energy content biomass feedstock; $\mathrm{FFE}_{\mathrm{biopower}}$ = fossil fuel equivalent of biopower = $E_{\mathrm{biopower}}/\eta_{\mathrm{electricity;}}$ $\eta_{\mathrm{electricity}}$ = efficiency of conventional power generation ≈ 0.4.

[2] Scenario A: energy crop productivity increases; food productivity constant. Scenario B: food productivity increases; energy crop productivity constant. Scenario C: both energy crop and food productivity increase. Calculations assume 2050 U.S. population is 419 million. Biofuel conversion yield assumed to be 91 gallons gasoline equivalent/dry ton biomass. Initial energy crop productivity (multiplier = 1) is assumed to be 5 dry tons/acre/year. Initial food production productivity is estimated at 2,425 lb/acre/year (only considers 442 acres of cropland). Per capita food consumption is estimated at 985 lb/year. The food conversion loss factor is estimated to be 0.27 kg food consumed/kg crop production. Food productivity, consumption, and loss values based on Heller and Keoleian (2000).

[3] In 2005, 75.1 million acres of corn grain were harvested in the U.S., about 80% of which was feed to livestock (~60 MM acres;) ; 71.4 million acres of soybeans were harvested, with 70% going to feed animals (~50 million acres); and 61.6 million acres of hay were harvested. In 2002, 62 million acres of cropland were used as pastureland. An estimated 20% of the 50 million harvested acres of wheat are used to feed livestock (~10 million acres). Additional crops that are primarily fed to animals include sorghum (6 million), oats (2 million), and barley (3 million). The total allocation for animal feed production, therefore, is an estimated 255 million acres, not including other crops commonly feed to livestock (e.g. millet, rye, peas, beans, lentils). Crop acreages from NASS, 2006. Pasture acreage from USDA, 2006. Corn grain and soybeans allocated to animal feed from Etherton et al., 2003. Wheat allocated to animal feed based on FAO, 2006.

[4] Geq = gasoline equivalent; CRP = Conservation Reserve Program. Current gasoline demand ≈ 140 billion gallons; current vehicle fleet efficiency ≈ 20 mpg; vehicular HDV/LDV energy = 0.28. Status quo processing assumes ethanol only fuel produced at efficiency of 28% of feedstock lower heating value (LHV). Advanced processing assumes co-production of ethanol and Fischer-Tropsch fuels; product profile (% feedstock LHV): EtOH 54%; FT diesel 10%; FT gasoline 6%.

REFERENCES

25x'25 Work Group: 2004, "25 x '25: Agriculture's Role in Ensuring U.S. Energy Independence," Ag Energy Working Group, [online] http://www.agenergy.info/, accessed July 2006.

Aden, A., Ruth, M., Ibsen, K., Jechura, J., Neeves, K., Sheehan, J., Wallace, B., Montague, L., Slayton, A., and Lukas, J.: 2002, "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover," NREL/TP-510-32438, National Renewable Energy Laboratory, Golden, CO, USA.

[ACEEE] American Council for an Energy-Efficient Economy: 1997, "Energy Innovations: A Prosperous Path to a Clean Environment," by ACEEE, Alliance to Save Energy, NRDC, Tellus Institute, and Union of Concerned Scientists; Report Number E974, ACEEE, Washington, DC, USA.

Argonne National Laboratory: 2005, "The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model," [online] http://www.transportation.anl.gov/software/GREET/index.html, accessed July 2006.

Avery, Dennis: 2006, "Farming for Ethanol Would Have Serious Consequences for Forests, Food Production." *Environmental News*, [online] http://www.heartland.org/Article.cfm?artId=19333, accessed July 2006.

Berndes, G., Hoogwijk, M., and van den Broek, R.: 2003, "The contribution of biomass in the future global energy supply: a review of 17 studies," *Biomass & Bioenergy*, 25, pp. 1–28.

Brown, Lester R.: 2004, *Outgrowing the Earth: The Food Security Challenge in an Age of Falling Water Tables and Rising Temperature*; W.W. Norton, New York, NYUSA, p 240.

Cook, J.H., Beyea, J., and Keeler, K.H.: 1991, "Potential Impacts Of Biomass Production In The United-States On Biological Diversity," *Annual Review of Energy and The Environment*, 16, pp. 401–431.

Cooper, M.: 2006, "50 by 2030: Why $3.00 Gasoline Makes the 50 Mile Per Gallon Car Feasible, Affordable, and Economic," Consumer Federation of America, [online] www.consumerfed.org/pdfs/50_by_2030.pdf, accessed July 2006.

[EIA] Energy Information Administration: 2006, *Annual Energy Outlook 2006*, DOE/EIA-0383 (2006), [online] www.eia.doe.gov/oiaf/aeo/, accessed July 2006.

Etherton, T.D., Bauman, D.E., Beattie, C.W., Bremel, C.W., Cromwell, G.L., Kapur, V., Wheeler, M.B., and Wiedmann, M.: 2003, *Biotechnology in Animal Agriculture: An Overview*, Issue Paper 23, The Council for Agriculture Science and Technology; Ames, IA, USA.

[FAO] Food and Agriculture Organization of The United Nations: 2006, "Food Outlook No. 1," [online] http://www.fao.org/docrep/009/j7927e/j7927e02.htm, accessed July 2006.

Farrell, A.E., Plevin, R.J., Turner, B.T., Jones, A.D, O'Hare, M., and Kammen, D.M.: 2006, "Ethanol Can Contribute to Energy and Environmental Goals," *Science*, 311, pp. 506–508.

Fischer, G. and Schrattenholzer, L.: 2001, "Global bioenergy potentials through 2050," *Biomass & Bioenergy*, 20, pp. 151–159.

Friedman, D.: 2003, "A New Road Ahead: The Technology and Potential of Hybrid Vehicles," Union of Concerned Scientists, [online] www.ucsusa.org/assets/documents/clean_vehicles/Hybrid2003_final.pdf, accessed July 2006.

Giampietro, M. and Pimentel, D.: 1990, "Alcohol And Biogas Production From Biomass," *Critical Reviews In Plant Sciences*, 9, pp. 213–233.

Giampietro, M., Bukkens, S.G.F, and Pimentel, D: 1992, "Limits To Population-Size – 3 Scenarios Of Energy Interaction Between Human-Society And Ecosystem," *Population And Environment*, 14, pp. 109–131.

Giampietro, M., Ulgiati, S., and Pimentel, D.: 1997, "Feasibility of large-scale biofuel production – Does an enlargement of scale change the picture?" *Bioscience*, 47, pp. 587–600.

Giampietro, M. and Ulgiati, S.: 2005, "Integrated assessment of large-scale biofuel production," *Critical Reviews In Plant Sciences*, 24, pp. 365–384.

Goodman, N. and Pimentel, D.: 1979, "Biomass Energy-Conversion As An Alternate Energy-Source," *Compost Science-Land Utilization*, 20, pp. 28–31.

Greene, N., Celik, F., Dale, B., Jackson, M., Jayawardhana, K., Jin, H., Larson, E., Laser, M., Lynd, L.R., MacKenzie, D., Mark, J., McBride, J., McLaughlin, S., and Saccardi, D.: 2004, *Growing Energy: How Biofuels Can Help End America's Oil Dependence*. Edited by Natural Resources Defense Council, New York, NY, USA, pp. 1–96.

Hallberg, M.C.: 2001, *Economic Trends in U.S. Agriculture and Food Systems Since World War II*, Iowa State University Press, Ames, Iowa, USA.

Heller, M.C. and Keoleian, G.A.: 2000, "Life Cycle-Based Sustainability Indicators for Assessment of the U.S. Food System," Center for Sustainable Systems, University of Michigan; Report No. CSS00-04, [online] http://www.public.iastate.edu/~brummer/papers/FoodSystemSustainability.pdf, accessed July 2006.

Hoffert, M.I., Caldeira, K., Benford, G., Criswell, D.R., Green, C., Herzog, H., Jain, A.K., Kheshgi, H.S., Lackner, K.S, Lewis, J.S., Lightfoot, H.D., Manheimer, W., Mankins, J.D., Mauel, M.E., Perkins, L. J., Schlesinger, M.E., Volk, T., and Wigley, T.M.L.: 2002, "Advanced technology paths to global climate stability: Energy for a greenhouse planet," *Science*, 298, pp. 981–987.

Hoogwijk, M., Faaij, A., Eickhout, B., de Vries, B., and Turkenburg, W.: 2005, "Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios," *Biomass & Bioenergy*, 29, pp. 225–257.

Hu, P., Jones, D., Reuscher, T., Schmoyer, R., and Truett, L.: 2000. "Projecting Fatalities in Crashes Involving Older Drivers 2000–2025," Oak Ridge National Laboratory, Oak Ridge, TN, USA.

Huesemann, M.H.: 2004, "The failure of eco-efficiency to guarantee sustainability: Future challenges for industrial ecology," *Environmental Progress*, 23, pp. 264–270.

Johansson, T.B., Kelly, H., Reddy, A.K.N., and Williams, R.H.: 1993, "A renewables-intensive global energy scenario," pp. 1071–1142, in: T.B. Johansson, H. Kelly, A.K.N. Reddy, R.H. Williams (eds) *Renewable Energy: Sources of Fuels and Electricity*, Island Press, Washington, DC, USA.

Jordan, J. and Powell, J., 2006: "The False Hope of Biofuels: For Energy and Environmental Reasons, Ethanol Will Never Replace Gasoline," *Washington Post*, Sunday, July 2, Page B07.

Kassler, P.: 1994, "Energy for Development," Shell International Petroleum Company, LTD, London, UK.

Kheshgi, H.S., Prince, R.C., and Marland, G.: 2000, "The potential of biomass fuels in the context of global climate change: Focus on transportation fuels,"*Annual Review of Energy and The Environment*, 25, pp. 99–244.

Kim, S. and Dale, B.E.: 2004, "Cumulative and Global Warming Impact from the Production of Biomass for Biobased Products," *Journal of Industrial Ecology*, 7(3–4), pp. 147–162.

Khosla, V.: 2006, "Imagining the Future of Gasoline: Separating Reality from Blue-sky Dreaming?" http://www.khoslaventures.com/resources.html.

Lave L.B., Griffin, W.M., and MacLean, H.: 2001, "The Ethanol Answer to Carbon Emissions," *Issues In Science And Technology*, 18, pp. 73–78.

Leemans, R., van Amstel, A., Battjes, C., Kreileman, E., and Toet, S.: 1996, "The Land Cover and Carbon Cycle Consequences of Large-scale Utilizations Of Biomass as an Energy Source," *Global Environmental Change*, 6(4), pp. 335–357.

Lovins, A.B., Datta, E.K., Bustnes, O.-E., Koomey, J.G., and Glasgow, N.J.: 2004, *Winning the Oil Endgame*, Rocky Mountain Institute, Snowmass, CO, [online] www.oilendgame.com, accessed June 2006.

Lubowski, R.N., Vesterby, M., Bucholtz, S., Baez, A., and Roberts, M.J.: 2006, "Major Uses of Land in the United States, 2002," United States Department of Agriculture; Economic Research Service, Economic Information Bulletin Number 14, Washington, DC, USA.

Lynd, L.R., Cushman, J.H., Nichols, R.J., and Wyman, C.E.: 1991, "Fuel ethanol from cellulosic biomass," *Science*, 251(4999), pp. 1318–1323.

Lynd, L.R. and Wang, M.W.: 2004, "A Product Non-Specific Framework for Evaluating the Potential of Biomass-Based Products to Displace Fossil Fuels," *Journal of Industrial Ecology*, 7(3–4), pp. 17–32.

McLaughlin, S.B. and Kszos, L.A.: 2005, "Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States," *Biomass and Bioenergy*, 28, pp. 515–535.

McLaughlin, S.B., Kiniry, J.R., Taliaferro, C., and Ugarte, D.: forthcoming, "Projecting Yield and Utilization Potential of Switchgrass as an Energy Crop," *Advances in Agronomy*, 90, pp. 267–297.

McMurtrey, J.E., Daughtry, C.S.T., Devine, T.E., and Corp, L.A: 2005, Spectral Detection of Crop Residues for Soil Conservation from Conventional and Large Biomass Soybean. *Agronomy for Sustainable Development*, 25,pp. 25–33.

Morris, D.: 2005, *The Carbohydrate Economy, Biofuels, and the Net Energy Debate*, Institute for Local Self-Reliance, [online] www.ilsr.org/newrules/agri/netenergyresponse.pdf, accessed July 2006.

Nakićenović, N. and Swart, R.: 2000, *Special Report on Emissions Scenarios. A special report of Working Group III of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK.

[NASS] National Agricultural Statistics Service, 2006: *Acreage*, [online] http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1000, accessed July 2006.

National Research Council Report: 2000, "Biobased Industrial Products: Priorities for Research and Commercializatio," National Research Council and Committee on Biobased Industrial Products; National Academy Press, Washington, DC, USA.

Nonhebel, S.: 2002, Energy yields in intensive and extensive biomass production systems," *Biomass and Bioenergy*, 22, pp. 159–167.

Perlack, R.D., Wright, L.L., Turhollow, A.F., and Graham, R.L.: 2005, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, U.S. Department of Energy and U.S. Department of Agriculture, [online] feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf, accessed July 2006.

Pimentel, D.: 2001, *Biomass Utilization, Limits of. In Encyclopedia of Physical Science and Technology*, Third Edition, Vol 2, pp. 159–171, Academic Press, San Diego CA, USA.

Pimentel, D., Moran, M.A., Fast, S., Weber, G., Bukantis, R., Balliett, L., Boveng, P., Cleveland, C., Hindman, S., and Young, M.: 1981. "Biomass Energy From Crop And Forest Residues," *Science*, 212, pp. 1110–1115.

Pimentel, D., Fried, C., Olson, L., Schmidt, S., Wagnerjohnson, K., Westman, A., Whelan, A., Foglia, K., Poole, P., Klein, T., Sobin, R., and Bochner, A.: 1984, "Environmental And Social Costs Of Biomass Energy," *Bioscience*, 34, pp. 89–94.

Pimentel, D., Rodrigues, G., Wang, T., Abrams, R., Goldberg, K., Staecker, H., Ma, E., Brueckner, L., Trovato, L., and Chow, C.: 1994, "Renewable Energy – Economic And Environmental-Issues," *Bioscience*, 44, pp. 536–547.

Pimentel, D., Herz, M., Glickstein, M., Zimmerman, M., Allen, R., Becker, K., Evans, J., Hussan, B., Sarsfeld, R., Grosfeld, A., and Seidel, T.: 2002, Renewable energy: Current and potential issues," *Bioscience*, 52, pp. 1111–1120.

Pimentel, D. and Patzek, T.: 2005, "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower, *Natural Resources Research*, 14(1), pp. 65–76.

Policy Dialogue Advisory Committee: 1996, "Report to the President of the Interagency Steering Committee on the Outcome of Deliberation on the Policy Dialogue Advisory Committee to Assist in the Development of Measures to Significantly Reduce Greenhouse Gas Emissions From Personal Motor Vehicles," National Economic Council, Washington, DC, USA.

Reith, J.H, den Uil, H., van Veen, H., de Laat, W.T.A.M., Niessen, J.J., de Jong, E., Elbersen, H.W., Weusthuis, R., van Dijken, J.P., and Raamsdonk, L.: 2002, "Co-production of Bio-Ethanol, Electricity, and Heat from Biomass Residues," 12th European Conference and Technology Exhibition on Biomass for Energy, Industry, and Climate Protection, June 17–21, Amsterdam, The Netherlands, [online] http://www.senternovem.nl/mmfiles/28383_tcm24-124244.pdf, accessed July 2006.

Ross, M. and Wenzel, T.: 2002: "An Analysis of Traffic Deaths By Vehicle Type and Model," Report Number T021, American Council for an Energy-Efficient Economy, Washington, DC, USA.

Sheehan, J., Aden, A., Paustian, K., Killian, K., Brenner, J., Walsh, M., and Nelson, R.: 2004, "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol," *Journal of Industrial Ecology*, 7(3–4), pp. 117–146.

Smil, V.: 2002, "Eating Meat: Evolution, Patterns, and Consequences," *Population and Development Review*, 28(4), pp. 599–639.

Swisher, J. and Wilson, D.:1993, "Renewable energy potential," *Energy*, 18(5), pp. 437–459.

Tiefenthaler, A.E., Goldman, I.L., and Tracy, W.F.: 2003, "Vegetable and Corn Yields in the United States: 1900 – Present," *HortScience*, 38(6), pp. 1–3.

Trainer, F.E.: 1995, "Can Renewable Energy Sources Sustain Affluent Society?" *Energy Policy*, 23, pp. 1009–1026.

Ulgiati, S.: 2001, "A comprehensive energy and economic assessment of biofuels: When 'green' is not enough," *Critical Reviews In Plant Sciences*, 20, pp. 71–106.

U.S. Census Bureau: 2006, "Population Estimates," [online] http://www.census.gov/popest/estimates.php, accessed July 2006.

U.S. Department of Agriculture: 2006, "Major Land Uses; Economic Research Service," [online] http://www.ers.usda.gov/Data/MajorLandUses/, accessed July 2006.

U.S. Department of Commerce and U.S. Census Bureau: 2003. *Statistical Abstract of the United States*, table 2 (resident population), [online] http://www.census.gov/statab/www, accessed April 2004.

[DOE] U.S. Department of Energy: 1993, *Evaluation of a potential wood-to-ethanol process. In Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector*, Technical Report 11, DOE/EP-0004, DOE, Washington, DC, USA.

[DOE] U.S. Department of Energy: 2002, "Martinez Refinery Completes Plant-Wide Energy Assessment," Best Practices Assessment Case Study, DOE/GO-102002-1618, [online] www.nrel.gov/docs/fy03osti/32615.pdf, accessed July 2006.

[EPA] U.S. Environmental Protection Agency: 2005, *Light-Duty Automotive Technology and Fuel Trends: 1975 through 2005* EPA420-S-05-001, [online] http://www.epa.gov/otaq/cert/mpg/fetrends/420s05001.htm, accessed July 2006.

Venturi, P. and Venturi, G.: 2003, "Analysis of Energy Comparison for Crops in European Agricultural Systems," *Biomass and Bioenergy*, 25, pp. 235–255.

Wackernagel, M., Schultz, N.B., Deumling, D., Callejas Linares, A., Jenkins, M., Kapos, V., Mongreda, C., Loh, J., Myers, N., Norgaard, R., and Randers, J.: 2002, Tracking the ecological overshoot of the human economy. *Proceedings of the National Academy of Sciences of the United States,* 99, pp. 9266–9271.

Weiss, M.A, Heywood, J.B., Drake, E.M., Schafer, A., and AuYeung, F.F.: 2000, *On the Road in 2020 – A Life Cycle Analysis of New Automobile Technologies*, Energy Laboratory Report # MIT 00-003, [online] http://lfee.mit.edu/public/el00-003.pdf, accessed July 2006.

Woods, J. and Hall, D.O.: 1994, *Bioenergy for Development – Technical and Environmental Dimensions*, FAO Environment and energy paper 13, Food and Agriculture Organization of the United Nations, [online] http://www.fao.org/docrep/t1804e/t1804e00.htm, accessed July 2006.

Wooley, R., Ruth, M., Sheehan, J., Ibsen, K., Majdeski H., and Galvez, A.: 1999, "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis Current and Futuristic Scenarios," NREL/TP-580-26157, National Renewable Energy Laboratory, Golden, CO, USA.

Wu, S., Lu, Y.-C., McMurtrey, J.E., Weesies, G., Devine, T.E., and Foster, G.R.: 2004, "Soil Conservation Benefits of Large Biomass Soybean (LBS) for Increasing Crop Residue Cover," *Journal of Sustainable Agriculture*, 24(1), pp. 107–128.

Yamamoto, H., Yamaji, K., and Fujino, J.: 1999: Evaluation of Bioenergy Resources with a Global Land Use and Energy Model Formulated with SD Technique. *Applied Energy*, 63, pp. 101–113.

CHAPTER 5

ENERGY MYTH FOUR – THE HYDROGEN ECONOMY IS A PANACEA TO THE NATION'S ENERGY PROBLEMS

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5.1. OVERVIEW

Americans must make their vehicles less polluting within the next two decades if the country is to avoid the serious and potentially catastrophic impacts of climate change. A growing scientific consensus is emerging which supports the argument that the nation and the world must reduce our emissions of greenhouse gases by more than 50% by 2050 to have high confidence of avoiding disastrous impacts. Yet it is an especially difficult target for the United States, since its population is likely to grow 50% during the next half-century and our GDP will triple. Whereas the average car on the road gets 20 miles per gallon (mpg) of gasoline today and new vehicles average only 24 mpg (NCEP, 2004, p. 8), fuel economy will have to jump to at least 60 mpg of gasoline in 2050.

Many people in the United States – including the President and Secretary of Energy – have promoted the use of hydrogen as a potential solution to these problems. Hydrogen, known to physicists as the simplest element, is an abundant resource, making up more than 90% of the composition of the universe. More aptly described as an "energy carrier" rather than a fuel source, hydrogen is frequently produced directly and indirectly through steam reforming (separating carbon from hydrogen using high powered steam), electrolysis (splitting water into oxygen and hydrogen), and photolysis (exploiting chemical reactions to produce hydrogen) (Berinstein, 2001; Petchers, 2003). Because the combustion of hydrogen produces no smoke or particulate matter (and when burned with oxygen produces water vapor as its only byproduct), politicians and energy analysts have been quick to proclaim hydrogen as a "silver-bullet" solution to the country's energy problems.

For example, President George W. Bush announced a $1.2 billion "Hydrogen Fuel Initiative" in his 2003 State of the Union Address (2003a). The program attempts

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to harness the energy potential of hydrogen as a way to power cars, trucks, homes, and businesses (DOE, 2005). As the President (2003b, para 2) remarked a few days after his address, “Hydrogen fuel cells represent one of the most encouraging, innovative technologies of our era … One of the greatest results of using hydrogen power, of course, will be energy independence for this nation.” Secretary of Energy Samuel W. Bodman (2006) recently insisted that the DOE was “working to meet the President’s goal of moving toward a hydrogen economy.” And the widely read DOE report *Toward a More Secure and Cleaner Energy Future for America* (2002) concludes that “hydrogen is a long-term solution to America’s energy needs, with near-term possibilities.” Title VII of the Energy Policy Act of 2005, for instance, authorized $3.28 billion for research and development on hydrogen.

However, this chapter promotes a starkly different view. Contrary to what many in the media may think, hydrogen cars are an exceedingly costly greenhouse gas strategy. Such cars are also an inefficient way to utilize renewable or zero-carbon primary energy resources, which will be critical to achieving any ambitious greenhouse gas target. In the near-term, the most cost-effective strategy for reducing emissions and fuel use is efficiency. Instead of hydrogen cars, a much better option remains the hybrid gasoline-electric vehicle, because it can reduce gasoline consumption and greenhouse gas emissions 30 to 50% with no change in vehicle class and hence no loss of jobs or compromise on safety or performance (Romm, 2004b). Because of these advantages, it, and not hydrogen powered automobiles, will likely become the dominant vehicle platform by the year 2020.

In the truly long-term, Americans will need to replace gasoline with a zero-carbon fuel. Yet all alternative fuel vehicle (AFV) pathways require technology advances and strong government action to succeed. Hydrogen is the most challenging of all alternative fuels, particularly because of the enormous effort needed to change our existing gasoline infrastructure. Unfortunately, we are many decades away from a time when hydrogen cars could be a cost-effective greenhouse gas mitigation strategy. Thus, devoting significant public resources to expensive hydrogen infrastructure and vehicles based on existing technologies is wildly premature.

As this chapter explores in greater detail, the most promising AFV pathway is a hybrid that can be connected to the electric grid. These so-called plug-in hybrids will likely travel three to four times as far on a kWh of electricity as fuel-cell vehicles (Romm and Frank, 2006). Ideally these advanced hybrids would also be a flexible fuel vehicle capable of running on a blend of biofuels and gasoline. Such a car could travel 500 miles on one gallon of gasoline (and five gallons of cellulosic ethanol) and have under one-tenth the greenhouse gas emissions of current hybrids (Romm, 2004b).

5.2. CLIMATE CHANGE AND SEA RISE IMPACTS

Many analyses of transportation and energy focus on three issues: climate, energy security, and urban air pollution. Vehicle emissions of such pollutants, however, have been declining steadily, and by 2010, federal and state standards will make new U.S. cars exceedingly clean. The security dangers posed by over-reliance on oil from unstable regions of the world are serious but they pale with the security risks posed by climate change, as I will discuss. Also, addressing the climate issue will directly address the energy security issue, by leading to more efficient use of oil and substitution of oil with low-carbon alternatives, whereas addressing the energy security issue will not necessarily address the climate issue, but may in fact lead to greater use of unconventional oil, much of which, such as coal to diesel, shale, and heavy oil, is far more carbon intensive than conventional oil. So this chapter focuses exclusively on transportation and climate issues.

The need for action on climate change is more urgent than is widely understood. The scientific evidence is simply accumulating faster than can be captured in the international process for releasing consensus-based reports every five or six years. For instance, the last major report by the U.N.'s Intergovernmental Panel on Climate Change (IPCC) was published in 2001. To understand what is happening, we need to look at more recent studies and analyses.

According to the Arctic Climate Assessment, a comprehensive 2004 analysis by the top scientists from the nations that border the Arctic Circle, including ours, if we keep up current emissions trends, "warming over Greenland is likely to be of the magnitude that would eventually lead to a virtually complete melting of the Greenland Ice Sheet, with resulting sea level rise of about seven meters (23 feet) (IASC, 2004). Twenty-three feet sea level rise would be devastating to the nation (and the world). Yet we are close to the point of no return for Greenland melting, and, worse still, 23 feet is far from being the worst-case scenario (Hansen, 2005a).

In April 2005, James Hansen, director of NASA's Goddard Institute for Space Studies, added: "There can no longer be genuine doubt that human-made gases are the dominant cause of observed warming" (Hansen, 2005b). Hansen led a team of scientists that made "precise measurements of increasing ocean heat content over the past 10 years," which revealed the earth is absorbing far more heat than it is emitting to space, confirming earlier computer models of warming (Hansen et al., 2005a). Hansen called this energy imbalance the "smoking gun" of climate change (Hansen, 2005b; Hansen et al., 2005b).

Global concentrations of carbon dioxide, the primary heat-trapping greenhouse gas, are rising at an accelerating rate in recent years – and they are already higher than at any time in the past 3 million years. Bob Corell, the lead scientists of the 2004 Arctic Climate Assessment, reports that "Greenland is melting much more rapidly in the past two or three years than anyone imagined possible" (Woodward, 2005). Worse, the ocean's heat content will keep reradiating heat into the earth's atmosphere even after we eliminate the heat imbalance, meaning the planet will keep warming and the glaciers keep melting for decades after we cut greenhouse gas emissions. It is therefore imperative that we act in an "anticipatory" fashion and reduce emissions long before climate change is painfully obvious to everyone.

The planet has warmed about 0.8 °C since the mid-19th-century, primarily because of human-generated greenhouse gas emissions (Hansen et al., 2005b).

If we don't sharply reverse the course of global greenhouse gas emissions rise within the next decade, we will be committing the world to an additional 1 °C of warming, probably by mid-century (Hansen, 2005a). The last time the earth was more than 1 °C warmer than it is today, sea levels were 15–20 feet higher (Hansen, 2005a). That occurred during the Eemian interglacial period about 1,25,000 years ago, when Greenland appears to have been largely ice-free (Hansen, 2005a, 2005c).

How fast can the sea level rise? Following the last ice age, the world saw sustained melting that *raised sea levels more than a foot a decade* (Hansen, 2005a). James Hansen believes we could see such a catastrophic melting rate within the century (Hansen, 2005a). Moreover, sea levels ultimately could rise much more than 20 feet (Hansen, 2005a). If we don't sharply reverse the course of global greenhouse gas emissions rise by 2040, we would be headed towards an additional 3 °C warming, temperatures not seen for millions of years, when much of Antarctica was also melted and sea levels were 80 feet higher (Hansen, 2005a). Imagine the profound effects an 80-foot sea-level rise would have on this country.

Right now, the melting of the West Antarctica is counterbalanced by the increased snowfall over East Antarctica, which is also caused by global warming (as higher temperatures cause more atmospheric moisture and hence more precipitation). But the glacial thinning in West Antarctica has accelerated dramatically since the 1990s, and the entire ice shelf has begun disintegrate (Hansen, 2006). It is only a matter of time and temperature rise before Antarctica begins making its major contribution to sea level rise (Hogan, 2005).

5.3. CLIMATE AND CARS

To have a serious chance of avoiding such apocalyptic consequences, the world needs to avoid the additional 1 °C of warming that threatens the melting of Greenland. That, in turn, necessitates deep reductions in greenhouse gas emissions by all nations, but most immediately by the industrialized nations, who are responsible for some 80% of all greenhouse gas emissions released since the dawn of the industrial revolution.

As one example of the kind of reductions required by climate change, California Governor Arnold Schwarzenegger committed the state in 2005 to reduce greenhouse gas emissions to 80% below 1990 levels by 2050 (Schwarzenegger, 2005). Prime Minister Tony Blair has committed to a 60% reduction by 2050. All industrialized nations, including the United States, need to achieve reductions of 60–80%.

Such ambitious targets will be difficult to reach given the growth in economic activity and population expected in the next several decades. Meeting even more relaxed targets would require a radical change in the nation's energy system, particularly transportation. Indeed, while converting the entire electricity grid to zero-carbon power is no easy task, it can be done straightforwardly, if expensively, using existing technology. But in a world of growing economic activity and population, dramatic reductions in the transportation sector require a quantum change in both the vehicles and the fuels.

To put the transportation problem in context, consider the following domestic statistics. Virtually all of the energy consumed by U.S. cars, sport utility vehicles, vans, trucks, and airplanes is still petroleum-based. Transportation is the source of about one third of U.S carbon dioxide emissions today, and it is projected to generate about one third of the 40% rise in U.S. carbon dioxide emissions forecast for 2030 (EIA, 2006).

Internationally, the situation is equally problematic. As Claude Mandil, Executive Director of the International Energy Agency (IEA), said in May 2004, "In the absence of strong government policies, we project that the worldwide use of oil in transport will nearly double between 2000 and 2030, leading to a similar increase in greenhouse gas emissions" (IEA, 2004).

Significantly, between 2003 and 2030, analysts predict that over 1400 GW of new coal capacity will need to be built. As David Hawkins, Director of Natural Resources Defense Council's Climate Center told the U.S. House Committee on Energy and Commerce in June 2003, these plants would commit the planet to total carbon dioxide emissions of some 500 billion metric tons over their lifetime unless "they are backfit with carbon capture equipment at some time during their life." Hawkins further explained that this number amounts to half the estimated total cumulative carbon emissions from all fossil fuel use globally over the past 250 years. (Hawkins, 2003)

It is critical that whatever strategy the world adopts to reduce greenhouse gas ("GHG") emissions in the vehicle sector does not undermine our efforts to reduce GHG emissions in the electricity sector. It is also critical to note that improved vehicle efficiency alone cannot on its own achieve an 80% reduction in transportation greenhouse gas emissions (especially with increased GDP and population growth). A zero-carbon alternative fuel will be required. With this caveat in mind, the discussion that follows will explore the AFV issue, hydrogen cars and the AFV that may be the most plausible alternative to hydrogen: the plug-in hybrid-gasoline vehicle.

5.4. ALTERNATIVE FUELS AND ALTERNATIVE FUEL VEHICLES

The federal government and others, such as California, have tried to promote alternatives to gasoline for many years. These alternatives include natural gas, methanol, ethanol, propane, electricity, and bio-diesel. Alternative fuel vehicles (AFVs) operate on these fuels, although many are dual-fueled, that is, they can also run on gasoline. The 1992 Energy Policy Act established the goal of having alternative fuels replace at least 10% of petroleum fuels in 2000, and at least 30% in 2010. Currently, alternate fuels consumed in AFVs substitute for less than 1% of total consumption of gasoline. A significant literature has emerged explaining this failure. (GAO, 2000; Flynn, 2002)

I will examine the two central problems facing alternative fuel vehicles and their fuels. First, they typically suffer from several marketplace disadvantages compared to conventional vehicles running on conventional fuels. Hence, they inevitably require government incentives or mandates to succeed. Second, they typically do not provide cost-effective solutions to major energy and environmental problems, which undermines the policy case for having the government intervene in the marketplace to support them.

On the second point, in September 2003, the U.S. Department of Transportation Center for Climate Change and Environmental Forecasting released its analysis, *Fuel Option for Reducing Greenhouse Gas Emissions from Motor Vehicles* (DOT, 2003). The report assesses the potential for gasoline substitutes to reduce greenhouse gas emissions over the next 25 years (DOT, 2003). It concludes that "the reduction in GHG emissions from most gasoline substitutes would be modest" and that "promoting alternative fuels would be a costly strategy for reducing emissions" (DOT, 2003).

Besides the question of whether AFVs deliver cost-effective emissions reductions, there have historically been several other barriers to AFV success, including: the high first cost for vehicle; on-board fuel storage issues (i.e. limited range); safety and liability concerns (not addressed in this article); high fueling cost (compared to gasoline); limited fuel stations and the chicken and egg problem regarding fueling infrastructure; and improvements in the competition (better, cleaner gasoline vehicles).

All AFVs that have so far been promoted with limited success – electric vehicles, natural gas vehicles, methanol vehicles, and ethanol vehicles – have each suffered from some of all of these barriers. It should be emphasized that only one of these barriers can be fatal to the adoption of AFVs or alternative fuels, even where other clear benefits are delivered. Electric vehicles deliver the clear benefit of zero tailpipe emissions, and can even have lower per mile costs than gasoline cars, but range, refueling, and first-cost issues have limited their success and caused most major auto companies to withdraw their electric vehicles from the marketplace (Romm, 2004b).

The chicken and egg problem – who will build and buy the AFVs if a fueling infrastructure is not in place and who will build the fueling infrastructure before the AFVs are built – remains the most intractable barrier. Consider that a 2002 analysis by Argonne National Laboratory found that "the hydrogen delivery infrastructure to serve 40% of the light duty fleet is likely to cost over $500 billion" (Mintz, 2002). Argonne achieves its high cost projections even though the study assumes considerable cost and performance gains in a relatively mature technologies, such as a 50% cost reduction in hydrogen compressors. Jeroen van der Veer, Royal Dutch/Shell's Vice Chair, said in April 2003, "We estimate that the initial investment required in the U.S. alone to supply just 2% of cars with hydrogen by 2020 is around $20 billion" (van der Veer, 2003).

So infrastructure costs can be enormous. Some cities in this country and around the world have had some success in introducing natural gas fleets for cars and buses. But fleets have been oversold as strategy for market penetration (Nesbitt and Sperling, 1998; Romm, 2004a). Ultimately, the question is whether fleets represent a way to jump-start the consumer market for alternative fuel vehicles. According to the GAO, "Several fleet managers and representatives of the automobile industry acknowledge it is unlikely that usage of alternative fuel vehicles by these fleets will convince the general public to buy them." (GAO, 2000) Thus, while fleets remain a possible entry market for some AFVs, a different strategy will be needed to achieve broad commercialization.

In the case of natural gas light-duty vehicles, the environmental benefits were oversold, as were the early cost estimates for both the vehicles and the refueling stations: As Peter Flynn observed, "Early promoters often believe that 'prices just have to drop' and cited what turned out to be unachievable price levels" (Flynn, 2002). One study concluded, "Exaggerated claims have damaged the credibility of alternate transportation fuels, and have retarded acceptance, especially by large commercial purchasers" (Flynn, 2002).

Moreover, all AFVs face the increasing "competition" from improved gasoline-power vehicles. Indeed, two decades ago when tailpipe emissions standards were being developed requiring 0.02 grams/mile of NO_x, few suspected that this could be achieved by internal combustion engine vehicles running on reformulated gasoline (Romm, 2004b). The new generation of hybrids – such as the Toyota Prius and Ford Escape – have substantially raised the bar for future AFVs. In contrast to most AFVs, these vehicles have no chicken and egg problem (since they can be fueled everywhere), no different safety concerns than other gasoline cars, a substantially *lower* annual fuel bill, *greater* range, a 30–50% reduction in greenhouse gas emissions, and a 90% reduction in tailpipe emissions (Romm, 2004b). The vehicles do cost a little more, but that is partly offset by a federal government tax credit for fuel-efficient hybrids and the large reduction in gasoline costs, even ignoring the performance benefits. Compare that to many AFVs, whose environmental benefits, if any, typically come at the expense not merely of a higher first cost for the vehicle, but a much higher annual fuel bill, a reduced range, and other undesirable attributes from the consumer's perspective.

5.5. EXPLORING THE HYDROGEN ALTERNATIVE

The possibility that hydrogen could solve many of the nation's energy and environmental problems has received growing attention in recent years. The biggest push came when President Bush announced a major hydrogen initiative in his 2003 State of the Union address:

> Tonight I'm proposing \$1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles. A single chemical reaction between hydrogen and oxygen generates energy, which can be used to power a car – producing only water, not exhaust fumes. With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen, and pollution-free.
>
> (Bush, 2003b)

The key elements of this vision are that practical hydrogen cars could be available by the early 2020s and that the cars be pollution free, which in turn requires a pollution-free source for the hydrogen itself and a device (fuel cell) for converting it into useful energy without generating pollution.

Fuel cells are small, modular electrochemical devices, similar to batteries, but which can be continuously fueled. For most purposes, you can think of a fuel cell as a “black box” that takes in hydrogen and oxygen and puts out electricity, heat, and a little bit of water. The electricity runs an electric motor, and from that perspective, the rest of the vehicle is much like an electric car. Internal combustion engine cars can also be modified to run on hydrogen, although they are considerably less efficient than fuel cell vehicles (Romm, 2004b).

The transition to a transportation system based on a hydrogen economy will be much slower and more difficult than widely realized. In particular, it is unlikely that hydrogen vehicles will achieve significant market penetration (greater than one third of new vehicles) by 2040. (Heywood, 2006)

Hydrogen cars face enormous challenges in overcoming each of the major historical barriers to AFV success. The central challenge for any AFV seeking government support beyond R&D is that the deployment of the AFVs and the infrastructure to support them must cost effectively address some energy or environmental problems facing the nation. Yet in the spring issue of *Issues and Science and Technology*, two hydrogen advocates, Dan Sperling and Joan Ogden of University of California at Davis, wrote, “Hydrogen is neither the easiest nor the cheapest way to gain large near- and medium-term air pollution, greenhouse gas, or oil reduction benefits.” (Sperling and Ogden, 2004) A 2004 analysis by Pacific Northwest National Laboratory concluded that even “in the advanced technology case with a carbon constraint…hydrogen doesn’t penetrate the transportation sector in a major way until *after 2035*.” (Geffen et al., 2004) A push to constrain carbon dioxide emissions actually delays the introduction of hydrogen cars because sources of zero-carbon hydrogen such as renewable power can achieve emissions reductions far more cost-effectively simply replacing planned or existing coal plants. As noted above, our efforts to reduce GHG emissions in the vehicle sector must not come at the expense of our efforts to reduce GHG emissions in the electric utility sector.

In fact, *Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*, a January 2004 study by the European Commission Center for Joint Research, the European Council for Automotive R&D, and an association of European oil companies, concluded that using hydrogen as a transport fuel might well *increase* Europe’s greenhouse gas emissions rather than reduce them. (JRC et al., 2004) That is because many pathways for making hydrogen, such as grid electrolysis, can be quite carbon-intensive and because hydrogen fuel cells are so expensive that hydrogen internal combustion engine vehicles may be deployed instead (which is already happening in California, see below). Using fuel cell vehicles and hydrogen from zero-carbon sources such as renewable power or nuclear energy has a cost of avoided carbon dioxide of more than $600 a metric ton, which is more than a factor of ten higher than most other strategies being considered today (JRC et al., 2004).

Furthermore, a number of major studies and articles have recently come out on the technological challenges facing hydrogen. Transportation fuel cells currently cost about $2,000/kW, some 50 times greater than the cost of internal combustion engines (DOE, 2003).

Even with the most optimistic assumptions, the fuel cell powered vehicle offers only a marginal efficiency improvement over the advanced [diesel]-hybrid and with no anticipation yet of future developments of IC engines. At $100/kW, the fuel cell does not offer a short term advantage even in a European market." (Oppenheim and Schock, 2004)

A prestigious National Research Council panel concluded a major report in February 2004 with a variety of important technical conclusions (NRC, 2004). For instance, the panel said, "The DOE should halt efforts on high-pressure tanks and cryogenic liquid storage.... They have little promise of long-term practicality for light-duty vehicles." A March 2004 study by the American Physical Society concluded that "a new material must be discovered" to solve the storage problem (APS, 2004). An analysis in the May 2004 issue of *Scientific American* stated, "Fuel-cell cars, in contrast [to hybrids], are expected on about the same schedule as NASA's manned trip to Mars and have about the same level of likelihood" (Wald, 2004).

There is a tendency in analyses of a future hydrogen economy to assume the end state – mass production of low-cost fuel cells, pipeline delivery, and so on. Yet while transportation fuel cells would undoubtedly be far cheaper if they could be produced at quantities of one million units per year, the unanswered question is who will provide the billions of dollars in subsidies during the many years when vehicle sales would be far lower and vehicle costs far higher. Additionally, while pipelines are the desired end game, and "the costs of a mature hydrogen pipeline system would be spread over many years," as the National Research Council panel noted, "the transition is difficult to imagine in detail" (NRC, 2004). The AFV problem is very much a systems problem where the transition issues are as much of the crux as the technological ones. It therefore follows that AFV analysis should be conservative in nature, stating clearly what is technologically and commercially possible today, and, when discussing the future, be equally clear that projections are speculative and will require both technology breakthroughs and major government intervention in the marketplace. Analysis should treat the likely competition fairly: If major advances in cost reduction and performance are projected for hydrogen technologies, similar advances should be projected for hybrids, batteries, biofuels, and the like. After all, AFVs must compete against the most efficient gasoline-power vehicles for market share.

My aim here is to be realistic, using analysis that is neither optimistic nor pessimistic. In almost every case where I cite a study, there are other studies with different conclusions based on different assumptions, on projections of future technological breakthroughs, or on estimates of how mass-production of existing technology could dramatically cut costs. I am very hopeful that the sunnier predictions ultimately prove true, but our limited experience with commercializing fuel cells provides a multi-decade lesson in high-tech humility. And our recent experience trying to accelerate the introduction of alternative fuel vehicles provides a recent lesson of how difficult it will be to rapidly change gasoline-powered cars and the gasoline infrastructure. One hard lesson learned is that over-hyping new technologies ultimately ends up slowing their success in the market.

A variety of major technology breakthroughs and government incentives will be required for hydrogen vehicles to achieve significant commercial success by the middle of this century. Continued research and development ("R&D") in hydrogen and transportation fuel cell technologies remains important because of their potential to provide a zero-carbon transportation fuel in the second half of the century. But neither government policy nor business investment should be based on the assumption that these technologies will have a significant impact in the near- or medium-term. Bill Reinert, U.S. manager of Toyota's advanced technologies group said in January 2005, absent multiple technology breakthroughs, we won't see high-volume sales of fuel cell vehicles until 2030 or later (Truett, 2005).

5.6. THE CALIFORNIA HYDROGEN HIGHWAY

Let us briefly consider the most ambitious proposal on the table in this country for deploying a hydrogen cars – the State of California. In his 2004 State of the State address, Governor Schwarzenegger announced, "I am going to encourage the building of a hydrogen highway" (Schwarzenegger, 2004). In May 2005, the blueprint plan for that highway was announced (CA EPA, 2005).

The blueprint established a multi-phase approach, where the first phase was 50–100 fueling stations and 2,000 hydrogen cars (1,200 fuel cell vehicles and 800 hydrogen internal combustion engine cars) (CA EPA, 2005). The goal is to achieve this in the 2010 timeframe. The network is supposed to achieve "30% reduction in greenhouse gas emissions relative to a comparable number of today's fuels and vehicles" (CA EPA, 2005). Over a longer period of time, Phase 2 calls for a "network of 250 hydrogen stations and 10,000 hydrogen vehicles" (CA EPA, 2005). Finally, in Phase 3, the number of stations remains the same but the number of hydrogen cars doubles to 20,000 (CA EPA, 2005).

From a GHG standpoint, hydrogen ICE vehicles are among the least attractive efficient vehicles imaginable. Hydrogen ICEs are likely to be far less efficient than fuel-cell vehicles and perhaps only 25% more efficient than gasoline ICEs (CA EPA, 2005). Therefore they are likely to have a reduced range because of the difficulty of storing large volumes of hydrogen onboard. Vehicle owners would directly experience the high price of hydrogen. As a result, annual vehicle ownership costs for mid-sized hydrogen ICE vehicles would be 30% higher than current gasoline vehicles (and only slightly lower than fuel-cell vehicles), according to a 2002 Arthur D. Little analysis (ADL, 2002).

Moreover, because of the energy consumed in generating hydrogen (from natural gas or electricity, for instance) and compressing hydrogen for storage, the "well-to-wheel" energy use of a hydrogen ICE vehicle may actually be higher than that of a gasoline ICE (Romm, 2004a). A 2002 analysis of ten different alternative fuel vehicles found that ICEs running on hydrogen from natural gas had the *lowest overall efficiency* on a life-cycle (well-to-wheel) basis (Kreith et al., 2002). Running an ICE car on hydrogen from natural gas would probably not save any greenhouse gas emissions compared with running a gasoline ICE car and would *increase* emissions compared to a hybrid gasoline-electric car (Romm, 2004a). Running an ICE car on hydrogen made from renewable electricity is one of the most wasteful uses of that renewable electricity conceivable, especially compared to using that renewable electricity to run a plug-in hybrid (see below) (Romm, 2004a). If mitigating global warming is the goal, hydrogen ICE cars are not a viable strategy for the foreseeable future.

The dilemma for California – or for the entire country should we decide to go down this route of accelerated deployment – seems apparent from the blueprint. While hydrogen ICE vehicles make very little sense from an environmental perspective, they do have the advantage of relatively lower cost. In Phase One, the state is only planning to offer a $10,000 per vehicle incentive for hydrogen cars (CA EPA, 2005). Since hydrogen fuel cell cars currently cost on the order of a $1 million apiece, and are unlikely to be even a factor of 10 less expensive in 2010, this incentive has essentially no impact on the cost of a hydrogen fuel cell car (Romm, 2004b). But $10,000 represents a substantial fraction of the added cost of an hydrogen ICE car. The end result is thus the perverse situation that the state is providing the maximum proportional subsidy to the least environmentally desirable new product. This merely serves to underscore the premature nature of the entire Hydrogen Highway effort.

When I was at the U.S. Department of Energy, the only reason we were interested in hydrogen – a fuel that is expensive, difficult to store in small volumes, and very inefficient to make – was the possibility that it could be converted with very high efficiency in fuel cells and because of the challenging technical hurdles that made it difficult for the private sector to justify investing without government cost-sharing. That very high efficiency was needed to compensate for the added cost, the storage problems, and the inefficiency in hydrogen generation.

As for hydrogen fuel cell vehicles, they still face major challenges to overcome each and every one of the barriers discussed in the previous section. It is possible we may never see a durable, affordable fuel cell vehicle with an efficiency, range, and annual fuel bill that matches even the best *current* hybrid vehicle (Brooks, 2004). Of all AFVs and alternative fuels, fuel cell vehicles running on hydrogen are probably the least likely to be a cost-effective solution to global warming, which is why the other pathways deserve at least equal policy attention and funding.

5.7. COMPARING PLUG-IN HYBRID AND HYDROGEN VEHICLES

5.7.1 Plug-In Hybrid Advantages

In contrast to the hydrogen vehicles, there is another AFV technology that appears to have clear environmental benefits – including substantially lower greenhouse gas emissions, a much lower annual fuel bill, a much longer range than current cars (with the added ability to fuel at home), and far fewer infrastructure issues than traditional AFVs. This AFV is the plug-in hybrid.

A straightforward improvement to the current generation of hybrids can allow them to be plugged into the electric grid and run in an all-electric mode for a limited range between recharging. Most vehicle use is for relatively short trips, such as commuting – half of American cars travel under 30 miles a day – followed by an extended period of time during which the vehicle is not being driven and could be charged. So even a relatively modest all-electric range of 20–30 miles could allow these vehicles to replace a substantial portion of gasoline consumption and tailpipe emissions. (Romm and Frank, 2006) If the electricity were from CO_2-free sources, then these vehicles would also have dramatically reduced net greenhouse gas emissions. Plug ins are unlikely to achieve significant market penetration until after 2020, which leaves plenty of time to begin the transition to clean electricity.

Because they have a gasoline engine, and are thus a duel-fuel vehicle, plug-in hybrids avoid two of the biggest problems of pure electric vehicles. First, they are not limited in range by the total amount of battery charge. If the initial battery charge runs low, the car can run purely on gasoline and on whatever charging is possible from the regenerative braking. Second, electric vehicles take many hours to charge, so that if for some reason owners were unable to allow the car to charge – either because they lacked the time between trips to charge or there was no local charging capability – then the pure-electric car could not be driven. Thus, plug-in hybrids combine the best of both hybrids and pure electric vehicles.

A conventional automobile costs about 12 cents a mile to operate at current gasoline prices. Amazingly, a plug-in hybrid could run on electrons at around three cents a mile at current electricity prices. Battery improvement will lead to increased functionality for plug-in hybrids. The larger battery of a plug-in hybrid, coupled with a higher-powered electric motor, allows significant downsizing of the gasoline engine and other related mechanical systems. Researchers at the University of California, Davis, have built plug-in hybrid prototypes that can travel 60 miles on electricity alone with engines that are less than half the size of standard engines. Their eight sedans and full-size SUVs are now undergoing testing. (Romm and Frank, 2006)

5.7.2 Plug-In Hybrid Barriers

Plug-in hybrids avoid many of the barriers facing most AFVs. Plug-in hybrids do not have a limited range. They do not have major safety and liability issues – although great care would have to be taken in the design of any home-based system that charged plug-in hybrids or allowed them to feed back into the grid. They do not have a high fueling cost compared to gasoline. In fact, the per-mile fueling cost of running on electricity is about one third the per-this mile cost of running on gasoline (Romm and Frank, 2006). The chicken and egg problem is minimized because electricity is

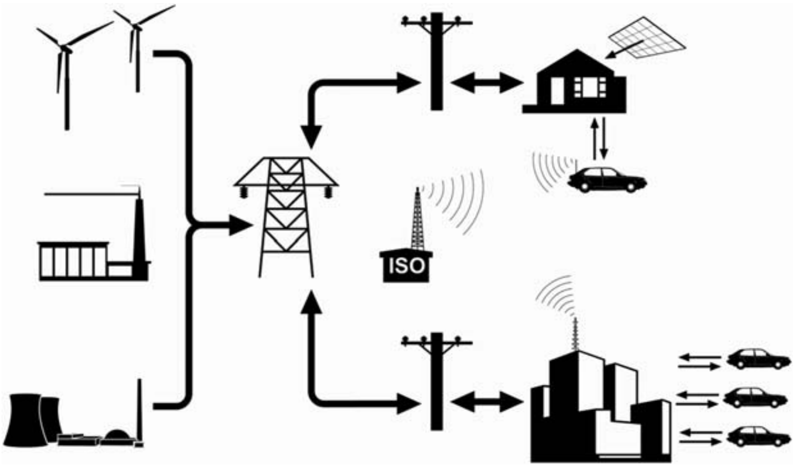

Figure 5.1. The direction of power flows with plug-in hybrid electric vehicles (Adapted from Kempton and Tomic, 2005)

widely available and charging is relatively straightforward. The direction of power flows with plug-in hybrid electric vehicles is illustrated in Figure 5.1.

The vehicle will almost certainly have a higher first cost, but this is likely to be more than compensated by the economic benefit of a lower fuel bill, as a 2003 study by the California Energy Commission and California Air Resources Board concluded (CEC and CARB, 2003). A 2006 study by TIAX found that for gasoline at three dollars a gallon – probably the low end of the price range by the time we begin a broad transition to plug ins in 2020 – the payback for the extra cost of the vehicle will be five years even if electricity prices rise 25% from current levels (TIAX, 2006).

Also, those studies did not consider a large potential revenue stream the vehicle owner may be able to extract from the utility by having what is essentially a portable electric generator. A plug-in hybrid owner may be able to extract revenue for grid regulation services – generators that can provide fast response when grid voltage needs to be increased or decreased (Brooks and Gage, 2001). Utilities would pay for this service if there was a guarantee that the car could deliver juice when needed, which suggests that this is more practical for vehicle fleets or for a corporate sponsor. The potential value of such services is significant: $700–3,000 per year. (Letendre and Kempton, 2002). This value is so large that it might allow the monthly cost of purchasing or leasing a plug-in hybrid to be *lower* than a conventional car, and perhaps even cover the replacement cost for batteries. It is critical that we fund some real-world demonstrations of plug-in hybrids providing these services, to see if this value can be extracted. If it can, we might see major utilities helping to subsidize the cost and/or financing of plug-in hybrids.

Environmentally, plug-in hybrids offer significant potential benefits over hydrogen vehicles. First, since they are designed to run all-electric for short trips such as commuting, they offer the possibility of being zero-emission vehicles (ZEVs) in cities. The best early uses of plug-in hybrids may well be to replace dirty diesel engine vehicles used regularly in cities, such as buses, maintenance vehicles, and delivery trucks. If we are unable to overcome the multiple technical and practical hurdles to hydrogen fuel cell cars, then plug-in hybrids may be the only viable option for urban zero emission vehicles.

The potential greenhouse gas benefits of plug-in hybrids are even more significant, if a source of zero-carbon electricity can be utilized for recharging. No AFV can by itself bring about a transition to zero-carbon electricity – that will require action by government. But plug ins have an enormous advantage over hydrogen fuel cell vehicles in the utilization of zero-carbon electricity. That is because of the inherent inefficiency of generating hydrogen from electricity, transporting hydrogen, storing it onboard the vehicle, and then running it through the fuel cell. The total well-to-wheels efficiency with which a hydrogen fuel cell vehicle might utilize electricity is roughly 20% (although that number could rise to 25% or a little higher with the kind of multiple technology breakthroughs required to enable a hydrogen economy) (Brooks, 2004; Romm and Frank, 2006). The well-to-wheels efficiency of charging an onboard battery and then discharging it to run an electric motor in an plug-in hybrid, however, is 80% (and could be higher in the future) – four times more efficient than current hydrogen fuel cell vehicle pathways (Brooks, 2004; Romm and Frank, 2006).

As Dr. Alec Brooks, a leading electric vehicle designer has shown, "Fuel cell vehicles that operate on hydrogen made with electrolysis consume four times as much electricity per mile as similarly-sized battery electric vehicles" (Brooks, 2004). Ulf Bossel, founder of the European Fuel Cell Forum, comes to a similar conclusion in a recent article, "The daily drive to work in a hydrogen fuel cell car will cost four times more than in an electric or hybrid vehicle" (Morris, 2003; Bossel, 2004).

This relative inefficiency has enormous implications for achieving a sustainable energy future. To replace half of U.S. ground transport fuels (gasoline and diesel) in the year 2050 with hydrogen from wind power, for example, might require 1400 gigawatts of advanced wind turbines or more (Romm, 2004b). To replace those fuels with electricity in plug-in hybrids might require under 400 gigawatts of wind (Romm, 2004b). That 1000 GW difference may represent an insurmountable obstacle for hydrogen as a GHG mitigation strategy – especially since the U.S. will need several hundreds of gigawatts of wind and other zero-carbon power sources in 2050 just to sharply reduce GHG emissions in the electricity sector.

With modified internal-combustion engines, plug-in hybrids could also run on a mixture of 15% gasoline and 85% biofuel. These kinds of vehicles could travel 500 miles on one gallon of gasoline blended with five gallons of ethanol and thus constitute a long-term strategy for dealing with the inevitable peak and subsequent decline in world oil supplies. Perhaps the best biofuels for cars is cellulosic ethanol.

5.7.3 Cellulosic Ethanol

Biomass can be used to make a zero-carbon transportation fuel, like ethanol, which is now used as a gasoline blend. Today, the major biofuel is ethanol made from corn, which yields only about 25% more energy than was consumed to grow the corn and make the ethanol, according to some estimates. Considerable R&D is improving the production of ethanol from sources other than corn. This so-called cellulosic ethanol can be made from agricultural and forest waste as well as dedicated energy crops, such as switchgrass or fast-growing hybrid poplar trees, which can be grown and harvested with minimal energy consumption, so overall net emissions are near zero (Lave et al., 2000, 2001).

All cars today can use a mixture of 10% ethanol and 90% gasoline, E10. Some four million flexible-fuel vehicles, which can run on either gasoline or E85, are on the road today, but few use E85 because of its high price and the under-developed refueling infrastructure. This suggests that we cannot solve the chicken and egg problem for an alternative fuel merely by delivering a cost-effective vehicle capable of running on that fuel.

The big advantage ethanol has over alternative fuels like hydrogen (and natural gas) is that it is a liquid fuel and thus much more compatible with our existing fueling system. Existing oil pipelines, however, are not compatible with ethanol, so significant infrastructure spending would still be required if ethanol were to become the major transportation fuel (Bryan, 2002). Ethanol production will require major technological advances before matching the price of gasoline on an equivalent energy basis. Lester Lave and two other Carnegie Mellon University researchers present the following calculation:

> Producing cellulosic ethanol costs about $1.20 per gallon (1.80 per gallon, gasoline equivalent, since ethanol has two-thirds of the energy of a gallon of gasoline). Assuming that the per-gallon distribution costs are the same for ethanol and holding total tax revenue constant, ethanol would sell for $1.80 per gallon at the pump. However, this is equivalent to $2.70 per gallon in order to get as much energy as in a gallon of gasoline.
>
> (Lave et al., 2001; Greene and Schafer, 2003; calculation includes 20¢/gallon tax on ethanol)

This calculation should be viewed as a projection – given that the world is only at the very beginning stages of commercializing cellulosic ethanol. Nonetheless, it suggests two things. First, if oil prices in, say, 2020 are higher than they are today, then cellulosic ethanol will represent a potentially quite competitive alternative fuel. This is particularly true since a price for carbon is virtually inevitable by 2020, further improving the relative cost competitiveness of cellulosic ethanol to gasoline. The average price of gasoline in the United States has repeatedly spiked above $2.50 a gallon with oil at more than $60 a barrel.

If our goal is to reduce greenhouse gas emissions in the vehicle sector, our first strategy must be fuel efficiency, since efficiency holds the potential of paying for itself in fuel savings. That strategy buys us time to commercialize cellulosic ethanol in significant enough quantities to impact transportation greenhouse gas emissions.

It is possible that with technological progress and economies of scale in production plants, cellulosic ethanol could drop to under \$2.00 per gallon of gasoline equivalent.

The second conclusion we might draw from cost projections for cellulosic ethanol is that if we can develop a substantial biomass resource for the purpose of creating a low-carbon fuel, it will almost certainly be more cost-effectively used to make cellulosic ethanol than hydrogen. As the National Research Council concluded in 2004, "hydrogen production from biomass is a thermodynamically inefficient and expensive process, in which approximately 0.2–0.4% of the total solar energy is converted to hydrogen at a price of currently about \$7.05/kg H2 by gasification in a midsize plant." Even with major technology breakthroughs, "the committee estimates the possible future technology price for hydrogen from gasification of biomass to be \$3.60/kg H2, which is noncompetitive relative to other hydrogen production technologies." (NRC, 2004).

For hydrogen production from biomass, perhaps the biggest problem is how expensive and energy-intensive it is to transport hydrogen over long distances. Unfortunately, large biomass resources tend to be quite distant from population centers where vehicle fuel is most needed, and transporting solid biomass is also very expensive and energy intensive. Converting that biomass to a liquid fuel like cellulosic ethanol and then transporting that fuel is likely to be the most cost effective and least energy-intensive way of delivering a low-carbon bio-based fuel. A particularly significant benefit of using biomass to make cellulosic ethanol rather than hydrogen is that the switchover to ethanol can be done gradually, as more and more ethanol is blended with gasoline, whereas any switchover to hydrogen almost certainly requires a massive government subsidy for the infrastructure to attempt to solve the chicken-and-egg problem.[1]

Probably the biggest barrier to biofuels, and to biomass energy in general, is that biomass is not very efficient at converting and storing solar energy, so large land areas are needed to provide enough energy crops if biofuels are to provide a significant share of transportation energy. One 2001 analysis by ethanol advocates concluded that to provide enough ethanol to replace the gasoline used in the light-duty fleet, "it would be necessary to process the biomass growing on 300 million to 500 million acres, which is in the neighborhood of one-fourth of the 1.8 billion acre land area of the lower 48 states" and is roughly equal to the amount of all U.S. cropland in production today (Lave et al., 2001). That amount of displaced gasoline represents about 60% of all U.S. transportation-related carbon dioxide emissions today, but under 40% of what is projected for 2025 under a business-as-usual scenario. Given the acreage needed, using so much land for these purposes would obviously have dramatic environmental, political, and economic implications. More recently, the National Commission on Energy Policy developed an aggressive scenario that displaced the fuel for half of the nation's current passenger car fleet with ethanol grown from 30 million acres. This scenario was contingent on doubling crop yields, improved conversion processes, and doubling average automotive efficiencies (NCEP, 2004).

Thus, if ethanol is to represent a major transportation fuel in the coming decades, then U.S. vehicles will need to become much more fuel-efficient. Doubling the efficiency of the fleet by 2030 with hybrid engines and other advanced technology would cut biomass acreage requirements in half. And putting cellulosic ethanol blends into plug-in hybrids would further reduce acreage requirements, especially since there are plausible strategies for cogeneration of biofuels and biomass electricity.

In the long-term, biomass-to-energy production could be exceedingly efficient with "bio-refineries" that produce multiple products. Lee Lynd, professor of engineering at Dartmouth, described one such future bio refinery where cellulosic ethanol undergoes a chemical pretreatment, then fermentation converts the carbohydrate content into ethanol, as carbon dioxide bubbles off (L. Lynd, personal communication, 2003). The residue is mostly lignin (a polymer found in the cell walls of plants). Water is removed, and the biomass residue is then gasified to generate electricity or to produce a stream of hydrogen and carbon dioxide. The overall efficiency of converting the energy content of the original biomass into useful fuel and electricity would be 70%, even after accounting for the energy needed to grow and harvest the biomass. The carbon dioxide can be sequestered. Also, this process could be used to generate biodiesel. This is admittedly a futuristic scenario, but is the subject of intense research, and could make ethanol directly competitive with gasoline, and biomass electricity competitive with other zero-carbon alternatives, especially when there is a price for avoiding carbon dioxide emissions.

5.8. CONCLUSION AND RECOMMENDATIONS

We must change our transportation policy if we are to address rising greenhouse gas emissions and dependence on imported oil. Avoiding serious climate change will almost certainly require a significant reduction in projected U.S. transportation greenhouse gas emissions by 2025 – and a dramatic reduction in absolute emissions by 2050. Moreover, whatever strategy we use to reduce transportation carbon dioxide emissions must not interfere with our equally urgent efforts to minimize any increase in coal emissions and then to reduce those emissions.

The only plausible strategy for achieving significant reductions in projected vehicle petroleum use and CO_2 emissions by 2025 is fuel efficiency. For achieving 2050 targets, the best strategy is a plug-in hybrid running on a combination of low-carbon electricity and a low-carbon liquid fuel, probably biomass-derived. The hydrogen fuel cell is the alternative fuel vehicle (that has the most technical and infrastructure hurdles and is the least efficient pathway for reducing greenhouse gas emissions and utilizing renewable resources. Given these conclusions, the following recommendations would:

Phase in CO_2-related standards for cars and light trucks. California passed legislation in 2002 to cut the vehicular emissions of greenhouse gases 30% by model year 2016, and a group of other states have followed suit (although car makers are challenging the effort in court). We should adopt that policy nationwide, perhaps stretching the target to a 33% reduction by 2020.

This translates to about 40 miles per gallon, which means that in 2020, new U.S. vehicles would be about as efficient as European vehicles will be by 2010. Absent such standards, emissions and imports will continue to grow sharply. There is no escape from a government mandated solution, whether in the form of CO_2 emissions standards or a rebate for efficient vehicles and feebate for inefficient vehicles. Absent a standard, much of the efficiency gain of new technologies will likely go towards providing increased vehicle acceleration and weight, as it has for the past two decades. Ideally, the government would adopt measures that would accelerate the market penetration of hybrids, particularly hybrid PZEVs (partial zero emission vehicles), since that is the best platform for the subsequent generation of vehicles needed to achieve absolute reductions in vehicle carbon dioxide emissions by 2050.

The single most effective strategy for reducing petroleum dependence over the next two decades would be the gradual and sustained phase-in of hybrid PZEV technology, capable of regenerative braking and at least 2 kWh of on-board storage per vehicle ton, across the entire vehicle fleet, reaching over 90% hybridization of all new vehicle classes by 2020. This could be achieved with a straightforward extension of current technology, near-term first-cost incentives to technology leaders, and government regulations increasing fuel efficiency, perhaps with a special credit for meeting efficiency standards with hybrid technology.

Ultimately, even stronger efficiency standards may be needed. A decision on a second phase of higher standards to begin in perhaps 2035 can probably be delayed until 2020, by which time we will have a much clearer understanding of just how severe global warming will be, of what the availability of conventional oil will be, and of which new efficiency and AFV technologies are cost effective.

Aggressively pursue plug-in hybrids. If PHEVs were to prove practical, they would probably be the ideal future platform for addressing all three major problems created by current vehicles: greenhouse gas emissions, tailpipe emissions, and oil consumption. PHEVs would likely require only one quarter to one third of the renewable electricity resources of hydrogen fuel cell vehicles for the same number of total vehicle miles traveled, and have a comparably lower per mile cost of operation. Federal and state governments should launch a major R&D effort to develop PHEVs and immediately begin pilot programs to see how they operate in real-world conditions. It is particularly important to learn if economic value can be derived from electric grid ancillary services, such as grid regulation, provided by PHEVs when they are not being driven. If so, they might have no price penalty compared to conventional vehicles. Also worth exploring is how to capture the air quality benefits from PHEVs running all-electric during ozone-alert days. PHEVs that are also *flexible-fuel vehicles capable of operating on gasoline or biofuel blends may be the ultimate vehicle.*

Aggressively promote biomass-derived fuel. The most plausible biofuel for delivering significant reductions in U.S. greenhouse gas emissions and oil consumption in the medium- and long-term is cellulosic ethanol. The National Commission on Energy Policy has developed a number of sensible policies in this area, including

- Develop the first six pioneer cellulose-to-energy plants between 2008 and 2012 using production or investment incentives
- Modify agricultural subsidies to include energy crops without increasing total farm subsidies or decreasing farm income (NCEP, 2004)

The biofuels effort should be far larger than the hydrogen effort. Research and development into synthetic diesel fuel made from a mixture of gasified coal and biomass should be pursued, accompanied by R&D into capturing and storing the hydrogen from this process. Ultimately, a renewable (or low-carbon) fuels standard will be beneficial, especially in helping to ensure that alternative fuels like hydrogen or synthetic diesel actually reduce greenhouse gas emissions.

Take a long-term, conservative perspective on hydrogen. While hydrogen might ultimately prove to be a viable and environmentally desirable alternative fuel post-2035, it is currently getting federal funding and policy attention that is vastly disproportionate to both its probability of success and its likely environmental benefits. This in turn has helped encourage a comparably disproportionate focus on hydrogen by state governments and private sector investors. Hydrogen should be viewed as a long-term, high-risk R&D effort, requiring at least three major scientific breakthroughs (fuel cell membranes, storage, and renewable hydrogen generation) before it is practical or desirable. It is worth continuing hydrogen R&D, but at least twenty years premature to be investing substantial funds in deploying vehicles or infrastructure. The only pilots that are justified are those that feed back directly into the R&D process. Also, hydrogen cars cannot be a cost-effective way to reduce greenhouse gas emissions until the government has sharply shifted our current energy policy and made CO_2-free power the primary source of U.S. electricity.

Some have argued that hydrogen fuel cell cars will allow us to avoid the difficult choices inherent in government mandates (Lovins and Cramer, 2004). Unfortunately, hydrogen is no alternative to government regulations; indeed, for hydrogen and fuel cell vehicles to become commercially successful, the federal government will have to intervene in the vehicle marketplace (and fuel marketplace and infrastructure marketplace) far more than it has ever done in the past. As the 2004 National Academy report on hydrogen noted,

> in no prior case has the government attempted to promote the replacement of an entire, mature, networked energy infrastructure before market forces did the job. The magnitude of change required. . .exceeds by a wide margin that of previous transitions in which the government has intervened.
>
> (NRC, 2004)

Thus the notion that the hydrogen economy is a panacea to the nation's energy problems is nothing more than a pervasive myth. And we may well find that in the race to avoid catastrophic global warming, hydrogen fuel cell cars never even make it to the finish line.

NOTE

[1] Another reason the cellulosic ethanol path seems more plausible is the high incremental cost of fuel-cell cars versus the relatively low incremental cost of cars modified to run on ethanol blends (or dual-fuel vehicles).

REFERENCES

[ADL] Arthur D. Little: 2002, *Guidance for Transportation Technologies: Fuel Choice for Fuel-cell Vehicles, Final Report*, Phase II Final Deliverable to DOE, 35340-00, Arthur D. Little, Cambridge, MA, Appendix, p. 107.

[APS] American Physical Society: 2004, "The Hydrogen Initiative", Washington, DC, American Physical Society, [online] www.aps.org/public_affairs/loader.cfm?url=/commonspot/security/getfile.cfm& PageID=49633, accessed July 2006.

Berinstein, Paula: 2001, *Alternative Energy: Facts, Statistics, and Issues*, Oryx Press New York, NY, USA.

Bodman, Samuel: 2006, "Secretary of Energy Appoints Hydrogen Technical Advisory Committee," [online] http://www.energy.gov/news/3758.htm, accessed July 2006.

Bossel, U.: 2004, "The Hydrogen Illusion," *Cogeneration & On-Site Power Production*, March–April, pp. 55–59.

Brooks, A.: 2004, "CARB's Fuel Cell Detour on the Road to Zero Emission Vehicles" *Evworld.com*, May, [online] www.evworld.com/library/carbdetour.pdf, accessed July 2006.

Brooks, A., and Gage, T.: 2001, "Integration of Electric Drive Vehicles with the Electric Power Grid – a New Value Stream," presented at the 18th International Electric Vehicle Symposium and Exhibition, October, Berlin, 2001, [online] www.acpropulsion.com/EVS18/ACP_V2G_EVS18.pdf, accessed July 2006.

Bryan, M.: 2002, "The Fuels Market – Biofuel Penetration and Barriers to Expansion," Presentation to *Conference on National Security and Our Dependence on Foreign Oil*, CSIS, Washington, DC, June, pp. 13–15, [online] www.csis.org/tech/biotech/other/Ebel.pdf, accessed July 2006.

Bush, G.W.: 2003a, *State of the Union Address*, [online] http://www.whitehouse.gov/news/releases/2003/01/20030128-19.html, accessed July 2006.

Bush, G.W.: 2003b, "Hydrogen Fuel Initiative can Make a Fundamental Difference. Remarks on energy dependence at the National Building Museum," [online] http://www.whitehouse.gov/news/releases/2003/02/20030206-12.html, accessed April 2006.

CA EPA: 2005, *California Hydrogen Blueprint Plan*, [online] www.hydrogenhighway.ca.gov/plan/reports/volume1_050505.pdf and www.hydrogenhighway.ca.gov/plan/reports/volume2_050505.pdf, accessed July 2006.

CEC and CARB: 2003, "Reducing California's Petroleum Dependence," Joint Agency Report, California Energy Commission and California Air Resources Board, Sacramento, CA, USA.

[EIA] Energy Information Administration: 2005, A*nnual Energy Outlook 2005*, DOE/EIA-0383, US Department of Energy Washington, DC, USA.

[EIA] Energy Information Administration: 2006, *Annual Energy Outlook 2006*, DOE/EIA-0383(2006), Washington, DC, [online] http://www.eia.doe.gov/oiaf/aeo/, accessed June 21, 2006.

Flynn, P.: 2002, "Commercializing an Alternate Vehicle Fuel: Lessons Learned From Natural Gas For Vehicles," *Energy Policy* Vol. 30, pp. 613–619.

[GAO] General Accounting Office: 2000, "Energy Policy Act of 1992: Limited Progress in Acquiring Alternative Fuel Vehicles and Reaching Fuel Goals," GAO/RCED-00-59, U.S. General Accounting Office, Washington, DC, USA.

Geffen, C., Edmonds, J., and Kim, S.: 2004, "Transportation and Climate Change: The Potential for Hydrogen Systems," *Environmental Sustainability in the Mobility Industry: Technology and Business Challenges*, SAE World Congress, Detroit, MI., SP (Society of Automotive Engineers), Vol. 1865, pp. 13–20, SAE International, Warrendale, PA, USA.

Greene, D. and Schafer, A.: 2003, "Reducing Greenhouse Gas Emissions from U.S. Transportation," Pew Center on Global Climate Change, Arlington, VA, USA, p. 30.

Hansen, J.: 2005a, "A Slippery Slope," *Climate Change* 68, 269–279, [online] www.columbia.edu/~jeh1/hansen_slippery.pdf, accessed July 2006.

Hansen, J.: 2005b, "Answers about the Earth's Energy Imbalance," [online] www.earthinstitute.columbia.edu/news/2005/story11-04-05.html, accessed July 2006.

Hansen, J.: 2005c, "Is There Still Time to Avoid 'Dangerous Anthropogenic Interference' with Global Climate?" presentation of December 6, 2005, to American Geophysical Union, San Francisco, California, [online] www.columbia.edu/~jeh1/keeling_talk_and_slides.pdf, accessed July 2006.

Hansen, J.: 2006, "Can We Still Avoid Dangerous Human-Made Climate Change?" presentation of February 10, 2006, at New School University, New York, [online] http://www.columbia.edu/~jeh1/newschool_text_and_slides.pdf, accessed July 2006.

Hansen, J., Nazarenko, Larissa, Ruedy, Reto, Sato, Makiko, Willis, Josh, Del Genio, Anthony, Koch, Dorothy, Lacis, Andrew, Lo, Ken, Menon, Surabi, Novakov, Tica, Perlwitz, Judith, Russell Gary, Schmidt, Gavin A., and Tausnev, Nicholas: 2005a, "Earth's Energy Imbalance: Confirmation and Implications," *Science* 308: 1431–1435, [online] http://www.columbia.edu/~jeh1/hansen_imbalance.pdf, accessed July 2006.

Hansen, J., Ruedy, R., Sato, M., and Lo, K.: 2005b, "GISS Surface Temperature Analysis: Global Temperature Trends: 2005 Summation," NASA website [online] http://data.giss.nasa.gov/gistemp/2005/, accessed July 2006.

Hawkins, D.: 2003, Testimony, U.S. House Committee on Energy and Commerce, Subcommittee on Energy and Air Quality, June 24, 2003, [online] www.nrdc.org/globalWarming/tdh0603.asp, accessed July 2006.

Heywood, John B: 2005, "New Vehicle Technologies: How Soon Can They Make a Difference?" *MIT Laboratory for Energy & Environment Newsletter*, [online] at http://lfee.mit.edu/ public/e%26e_March1.pdf%203, accessed July 2006.

Hogan, J.: 2005, "Antarctic Ice Sheet is an Awakened Giant," *New Scientist* 133(8), February 2, [online] http://www.newscientist.com/channel/earth/dn6962, accessed July 2006.

[IASC] International Arctic Science Committee: 2004, *Impacts of a Warming Arctic*, Cambridge University Press, New York, NY, USA.

[IEA] International Energy Agency: 2004, "Biofuels for Transport Press Release," International Energy Agency, Paris, [online] www.iea.org/Textbase/press/pressdetail.asp?PRESS_REL_ID=127, accessed July 2006.

JRC, EUCAR, and CONCAWE: 2004, *Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context. Brussels*, Joint Research Centre of the EU Commission, [online] http://ies.jrc.cec.eu.int/Download/eh/31, accessed July 2006.

Kreith, F., West, R.E., and Isler, B.: 2002, "Legislative and Technical Perspectives for Advanced Ground Transportation Systems," *Transportation Quarterly*, Vol. 56, No. 1, Winter 2002, pp. 51–73.

Lave, L., MacLean, H., Henrickson, C., and Lankey, R.: 2000, "Life-Cycle Analysis Of Alternative Automobile Fuel/Propulsion Technologies," *Environmental Science and Technology*, Vol. 34, pp. 3598–3605.

Lave L., Griffin W.M., and MacLean, H.: 2001, "The Ethanol Answer to Carbon Emissions," *Issues in Science and Technology*, Winter, [online] www.nap.edu/issues/18.2/lave.html, accessed July 2006.

Letendre, S. and Kempton, W.: 2002, The V2G [Vehicle to Grid] Concept: A New Model for Power?" *Public Utilities Fortnightly*, February 15, pp. 16–26.

Lovins, A. and Cramer, D.: 2004, "Hypercars, Hydrogen, and the Automotive Transition," *International Journal of Vehicle Design*, Vol. 35, pp. 50–85.

Mintz, M., Folga, S., Molburg, J., and Gillette, J.: 2002, "Cost of Some Hydrogen Fuel Infrastructure Options," Presentation to the Transportation Research Board, January 16, by Argonne National Laboratory, Argonne, IL, USA.

Morris, D.: 2003, "Is There a Better Way to Get from Here to There?" Institute for Local Self-reliance, Minneapolis, MN, USA.

[NCEP] National Commission on Energy Policy: 2004, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Needs*, Washington, DC, [online] www.energycommission.org, accessed July 2006.

[NRC] National Research Council: 2004, *The Hydrogen Economy*, National Academy Press, Washington, DC, [online] www.nap.edu/books/0309091632/html, accessed July 2006.

Nesbitt, K. and Sperling, D.: 1998, "Myths Regarding Alternative Fuel Vehicle Demand by Light-duty Vehicle Fleets," *Transport Res.-D.*, Vol. 3, No. 4, pp. 259–269, [online] http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1043&context=itsdavis, accessed July 2006.

Oppenheim, A. and Schock, H.: 2004, "Raison d'Etre of Fuel Cells and Hydrogen Fuel for Automotive Power Plants," Society of Automotive Engineers, Troy, MI, USA.

Petchers, Neil: 2003, *Combined Heating, Cooling & Power Handbook: Technologies & Applications*, The Fairmount Press, New York, USA.

Romm, J.: 2004a, *The Hype about Hydrogen: Fact and Fiction in the Race to Save the Climate*, Island Press, Washington, DC, USA.

Romm, J.: 2004b, *The Car and Fuel of the Future: A Technology and Policy Overview*, National Commission on Energy Policy, Washington, DC, USA.

Romm, J. and Frank, A: 2006, "Hybrid Vehicles Gain Traction," *Scientific American*, April.

Romm, J.: forthcoming, *Hell And High Water: Global Warming – The Solution and the Politics*, William Morrow, New York, NY, USA.

Schwarzenegger, A.: 2004, *State of the State Address*, January 6, [online] http://www.hydrogenhighway.ca.gov/vision/vision.htm, accessed July 2006.

Schwarzenegger, A.: 2005, *Executive Order S-3-05*, State of California Executive Department, Sacramento, CA, USA.

Sperling, D. and Ogden, J.: 2004, "The Hope for Hydrogen," *Issues in Science and Technology*, Spring.

TIAX LLC.: 2006, "Plug-in Hybrids: A Major Opportunity For The Electric Utility Industry," Cambridge, MA.

Truett, R.: 2005, "Volume fuel cell cars at least 25 years away, Toyota says," *Automotive News*, January 10, www.autonews.com/news.cms?newsId=11122, accessed July 2006.

[DOE] U.S. Department of Energy: 2002, *Towards a More Secure and Cleaner Energy Future for America: A National Vision of America's Transition to a Hydrogen Economy – to 2030 and Beyond*, [online] from http://hydrogen.energy.gov/pdfs/vision_doc.pdf, accessesd June 2006.

[DOE] U.S. Department of Energy: 2003, "Basic Research Needs for the Hydrogen Economy," Office of Science, Washington, DC, [online] www.sc.doe.gov/bes/hydrogen.pdf, accessed July 2006.

[DOE] U.S. Department of Energy: 2005, "President's Hydrogen Fuel Initiative," Department of Energy, Washington, DC, [online]http://www1.eere.energy.gov/hydrogenandfuelcells/presidents_initiative.html, accessed April 2006.

[DOT] U.S. Department of Transportation: 2003, *Fuel Options for Reducing Greenhouse Gas Emissions from Motor Vehicles*, DOT-VNTSC-RSPA-03-03, [online] http://climate.volpe.dot.gov/docs/fuel.pdf, accessed July 2006

van der Veer, J.: 2003, "Hydrogen – Fuel of the Future," Remarks at Iceland Hydrogen Economy Conference, 24 April, 2003.

Wald, M.: 2004, "Questions about a Hydrogen Economy," *Scientific American*, May, pp. 66–73.

Woodward, C.: 2005, "The Big Meltdown," *E/The Environmental Magazine*, February/March, [online] www.emagazine.com/view/?2302&printview&imagesoff, accessed July 2006.

CHAPTER 6

ENERGY MYTH FIVE – PRICE SIGNALS ARE INSUFFICIENT TO INDUCE EFFICIENT ENERGY INVESTMENTS

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When policymakers are pressed to defend government interventions in energy markets, they frequently cite the existence of market failures. And rightly so. Economists are almost uniformly of the opinion that markets should be left alone by government unless market failures are discovered. They go on to caution that government intervention will improve efficiency if – and only if – the prospective intervention remedies one or more of those market failures. And even if market failures exist, actual government policies may not improve market operations because politicians rather than economists design the policies.[1]

Most of those people who concern themselves with federal or state energy policy are convinced that energy markets are riddled with market failures.[2] That's why most energy initiatives forwarded by the Left and Right would have the government more involved in private decisions about energy production and consumption. While liberals and conservatives may disagree about *how* the government should intervene in energy markets, they largely agree about *whether* the government should intervene in energy markets. For instance, environmentalists think market actors will make poor decisions about electricity generation if left to their own devices, so they propose to subsidize or mandate the renewable energy technologies that might otherwise never be employed. Conservatives likewise think market actors will make poor decisions about electricity generation if left to their own devices, but they propose to subsidize nuclear energy rather than wind or solar energy.

Five characteristics of energy markets give rise to charges of energy market failure and, thus, provide the justification for government intervention.[3]

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 125–144

- Fossil fuels are a nonrenewable resource. The preferences of future generations are not properly reflected in the decisions made by producers and consumers in energy markets.
- Market actors respond sluggishly to energy price changes. The refusal of producers and consumers to respond quickly to high energy prices can cause inflation and recessions.
- Many residential consumers and commercial enterprises invest suboptimally in energy conservation.
- Consumers do not find the price of the substantial health, environmental, and national security costs reflected in energy prices. Thus, energy prices may be "too low."
- Government interference in energy markets via direct and indirect subsidies, production constraints, and the threat of future intervention distort price signals. Given this backdrop of longstanding and ongoing intervention, many people believe that free energy markets are – and always will be – a myth.

Those observations have led many to conclude that energy price signals are not accurate reflections of true energy costs and will not produce efficient energy production and consumption decisions. Various remedies have been suggested, ranging from corrective action to "get prices right" to more ambitious intervention to directly control production and consumption decisions.

We believe that the contention that energy markets are riddled with market failures, however, is a myth. While energy markets don't work with textbook efficiency (in fact, few do), energy markets do not exhibit special problems that require government attention. Energy prices are reasonably accurate reflections of true energy costs and the complaints lodged against them are greatly overstated. In those settings in which prices are not accurate reflections of total costs (primarily in electricity and retail gasoline markets), the best remedy is to eliminate government policies that distort prices rather than adopt countervailing interventions to offset the distortions caused by earlier policies.

6.1. ENERGY DEPLETION AND FUTURE GENERATIONS

Because fossil fuels are exhaustible, some argue that we need to ration production in order to save resources for future generations (Weiss, 1989; Barresi, 1997). Future generations, after all, have no say in energy markets, but their preferences regarding resource availability in the future must be considered. Markets won't provide that consideration, so government must do so.

Another version of this argument does not emphasize the rights of future generations. Instead, it paints a picture of inevitable future shortages as production declines occur. Fuel shortages will be accompanied by price hikes, recessions, and political struggle. Those unpleasant effects can be avoided if government starts planning now. "Intervention by governments will be required, because the economic and social implications of oil peaking would be otherwise chaotic." (Hirsch et al., 2005, p. 5).

It's important to note that this alleged market failure applies primarily to transportation rather than to electricity markets. That's because depletion fears are primarily directed at petroleum, and only a trivial amount of petroleum is used to generate electricity in the United States. (Deffeyes, 2005; Simmons, 2005) Recoverable coal and natural gas stocks – our main nonrenewable fuel sources in electricity markets – are generally thought to be quite plentiful. (World Energy Council, 2004; EIA, 2006)

Oil depletion concerns, however, rest on shaky ground. First, they are primarily about the future availability of *conventional* crude oil. Unconventional petroleum resources – such as those found in heavy bitumen, tar sands, and shale rock – are extremely plentiful and only lightly tapped at the moment because of high extraction costs.[4] Moreover, the technology exists to convert coal and natural gas to synthetic petroleum liquids, which means that other more plentiful fossil fuels could be harnessed to produce vast amounts of petroleum if the economics are favorable. Second, concerns that conventional crude oil is becoming scarce in any meaningful sense have not stood up well to serious scrutiny.[5]

If petroleum depletion were to become a genuine problem, would intergenerational equity demand conservation? We think not. The strongest normative argument against conservation is that it transfers resources from the relatively poor to the relatively rich (Landsburg, 1997). That's because today's generation is almost certainly much poorer than future generations. For instance, if per capita income grows at 2% a year, people 100 years from now will be approximately 7 times wealthier than we are today. Those concerned about intergenerational equity should worry more about standards of living today than about standards of living tomorrow.

The strongest positive argument against government intervention is that markets are more capable than government of reacting quickly and efficiently to declines in petroleum production. True declines, rather than temporary shocks, will permanently increase oil prices, which will induce investments in alternative energy sources and conservation.

But what about temporary (albeit multiyear) price shocks? If low prices most of the time and high prices some of the time are a problem, is there a market solution? Indeed there is. Long-term oil futures contracts are available to those worried about future price spirals.

The fact that marketers have not tried to offer long-term stable prices to consumers by arbitraging between the futures and retail markets suggests that most consumers believe that they benefit by accepting low prices most of the time in return for unpleasantly high prices some of the time. Said differently, we are "dependent" on oil exported from unstable countries rather than domestic oil or alternative sources of energy – and don't attempt to contract our way out of that instability – because it is cheaper in present value terms to do so.

The "solution" to oil price instability is to accept higher prices most of the time in return for lower prices some of the time. There is nothing wrong with such a trade-off as long as it is achieved through contract. 30-year fixed rate mortgages, for example, allow consumers to shift to others the risk of varying daily spot rates for borrowing (whose mean is lower but accompanied by higher variance) in return for higher mean and no variance (fixed) prices.

We don't, however, see those sorts of contracts in energy markets. Instead, what we see are proposals for European-style taxes on gasoline consumption, mandated alternative energy production, subsidies for the same, and regulations that require energy producers to retain excess production capacity.

Unlike contractual solutions, governmental solutions have the dubious distinction of being more expensive not just most of the time, but all of the time. That is the "alternatives" to fossil fuels are more expensive than conventional fossil fuels even when the latter prices are at peak, which is, of course, why such fuels are not embraced without government subsidy or coercion. For example, we have recently calculated that the federally owned Strategic Petroleum Reserve has cost the taxpayer between $65–80 per barrel (2004 dollars) to fill, which rivals the highest spot market prices ever recorded in the market (Taylor and Van Doren, 2005).

Market actors are more likely to work in the interests of future generations than are governmental actors. That's because democratically elected governments – and the regulatory agencies established by them – have a tendency to reflect the interests of swing voters in swing voting districts. Accordingly, it's unreasonable to expect governments to be more interested in the well-being of future generations than swing voters in swing districts who have short time horizons and political preferences.

Markets, on the other hand, can reflect longer time horizons. In fact, because the market value of assets is determined by expectations about what others might pay for them in the future, speculators represent future generations' interests in today's markets more effectively than politicians who follow swing voters, who's time horizon rarely spans past the next election.

6.2. OIL SHOCKS CAUSE RECESSIONS AND INFLATION

Energy supply and demand are relatively inflexible in the short run. As a consequence, small changes in either have very large effects on prices.[6] Over a longer time period, however, both supply and demand are very responsive to prices.[7]

The short-run inflexibility of producers or consumers – and the oil price shocks that result from such inflexibility – are alleged to be responsible for inflation and recessions. But not all economists agree. Ben Bernanke and his colleagues (1997), for instance, argue that different ("better") monetary policy would reduce the recessionary effect of oil shocks while Hamilton and Herrera (2004) argue that the potential for monetary policy is much more limited. The current oil price explosion that began in 2003 has caused far less economic harm than conventional wisdom predicted, which adds credence to those economists who have argued that the recessions that followed previous oil shocks were not caused by energy price spikes.[8]

Even though negative macroeconomic consequences may not follow oil shocks, the lack of supply and demand response in the short run leads to large transfers of wealth from consumers to firms in times of supply decreases (the Saudi and Texas booms of the 1970s and the current oil boom today) and firms to consumers in times of supply increases (the Saudi and Texas busts of the 1980s and late 1990s). While energy policy discussions often invoke macroeconomic or market failure rationales for government action, the most likely source of constituent demands for intervention in energy markets is the distributional concerns of firms and consumers. Both consumers and firms attempt to enlist the assistance of government to prevent those wealth transfers.

Energy market interventions, however, have failed to improve equity and done much to damage efficiency (Kalt, 1981; Van Doren, 1991; Taylor and Van Doren, 2006). The oil price-control system in the 1970s induced shortages and increased reliance upon imports at the time our stated policy was to reduce import dependency. Consumers were made worse off as a consequence (Taylor and Van Doren, 2006).

6.3. CONSUMER FAILURE

Claims that consumers fail to invest as much as they should in energy efficiency are legion. Explanations vary as to why consumers act irrationally, but common complaints include lack of information regarding prospective savings, cultural hostility to energy conservation, excessively conservative views about future energy prices, a lack of capital, the demand for irrationally high rates of return, and in some circumstances, the existence of a principal-agent problem (for instance, when landlords are making decisions about appliances but tenants will be paying the electricity bills that follow).[9]

How irrational are consumers when they make energy decisions? Empirical investigations find that consumers act far more rationally than many analysts believe. Clemson economist Molly Espey (2005), for instance, closely examined sales data from 2001 model automobiles and found that consumers actually *over-valued* the gains possible from buying fuel efficient vehicles. When households with mean incomes or higher purchase residential appliances, they appear to employ rationale discount rates when considering energy efficiency, but lower income households do not (Sutherland, 2003, pp. 8–12). While it's possible that low-income households are low-income for a reason (their time horizons are very short when it comes to trade-offs between well-being today and well-being tomorrow and they accordingly invest little in a whole host of things that economists say they *ought* to invest in, like education), some economists believe that their behavior in energy markets is actually reasonable efficient and perfectly defensible (Johnson and Kaserman, 1983; Nichols, 1992; Hassett and Metcalf, 1993; Metcalf and Rosenthal, 1995; Dixit and Pindyck, 1994; Metcalf, 1994). Finally, there is no evidence we are aware of to suggest that landlords select less energy efficient appliances for their properties than would have been selected by their renters had the decision been their's to make with their own money.[10]

Businesses might be expected to make more efficient decisions about energy consumption than residential households, but critics are even more convinced that businesses are leaving vast sums of money on the table. The premier example of gross corporate inefficiency marshaled by proponents of this argument is the reluctance of businesses to install high efficiency lighting ballasts. Although proponents argue that returns from such investments range from 37 to 199% (Koomey et al., 1995), closer analysis finds that the returns are wildly exaggerated and that businesses are acting efficiently by largely ignoring this technology (Ballonoff, 1999).

Other claims of market failure are also suspect. For example, many studies have been published that estimate how much energy might be saved from the full adoption of cost-effective energy efficient technology that is commercially available at any given time. Studies published by the Electric Power Research Institute (1993) and Arnold Fickett (Fickett et al., 1990), for example, contend that energy efficiency investments that cost up to the equivalent of 3 cents per kilowatt hour (a cost substantially below the cost of electricity) reduce electricity consumption from 30 to 70% respectively. Such findings suggest that many people make inefficient decisions in energy markets.

A test of this proposition, however, was conducted by the Denmark Institute for Local Government, which had calculated that corporate energy efficiency could be improved by 42% if only businesses would fully employ the profitable efficiency technologies available to them. After several years of extensive, on-site analysis, the institute concluded that only a 3.1% gain in energy efficiency could be realized through profitable energy efficiency investments – a figure so small that “the cost of finding electricity conservation projects is higher than the savings due to the realized investment.” The authors concluded that although “the background is experience from Danish industry; we judge the results as general for most industry” (Togeby and Larsen, 1995).

Even if consumers fail to make what might appear to be cost-effective conservation investments, it does not necessarily follow that governmental decisions will deliver net improvements in efficiency (Jaffe and Stavins, 1994). One study, for instance, found that federal energy efficiency standards for residential appliances actually increase consumers’ net costs by $46–52 billion through 2050 (Sutherland, 2003).[11] RAND economists David Loughran and Jonathan Kulick (2004) calculate that the $14.7 billion spent by electric power companies to subsidize ratepayer conservation investments between 1989 and 1999 (undertaken primarily at the behest of – and under the supervision of – state utility regulators) reduced mean electricity sales by only 0.2 and 0.4% at an average cost of 14–22 cents per kilowatt hour (much greater than the cost of additional electricity during that period).[12]

6.4. EXTERNALITIES

Analysts frequently argue that energy use causes environmental and human health damage whose costs are not reflected in energy prices. Economists describe such costs as “externalities” because they impose costs on others that are external to the prices that govern the transaction between buyer and seller. Because consumer prices don't include the full costs of energy, too much energy is consumed and government must intervene to achieve efficiency.

Economists' remedy for externalities is a tax that would quantify the cost of the externalities associated with each energy source in dollar terms. The tax would force consumers to pay the total social cost for their energy (which would "internalize the externality").[13] Revenues from energy taxes would be used to compensate those who are harmed by the energy consumed by others.

The underlying objective of energy taxes is to approximate the market that would arise if polluters had to compensate those harmed by pollution.[14] Polluters would then have to factor those payments into the prices they charged for goods and services. Pollution taxes are thus an attempt to mimic the market that would arise if third parties could hold producers liable for the damages caused by their pollution.

To "get prices right," the first step is to monetarize the health and environmental externalities associated with energy consumption. Unfortunately, we run into a serious problem here: The range of health and environmental externality estimates for each and every energy source that has appeared in the peer-reviewed literature are all over the map (Sundqvist and Soderholm, 2002). Estimates vary widely because experts do not agree about the relationship between small exposures to various substances and human health effects that result from those exposures.

The second step is to modify energy consumption decisions to take the health effects into account. Policymakers, however, prefer direct regulatory intervention rather than taxation to address externality issues for several reasons:

- Voters resist energy taxes but are more tolerant of direct environmental regulation because taxes impose visible costs while regulation imposes less visible costs;
- Energy taxes can yield uncertain amounts of pollution; regulation determines emission rates directly. Lawyers and environmentalists prefer the latter and are suspicious of pollution taxes, which are criticized as allowing firms to pay to pollute (Weitzman, 1974)[15];
- Regulation allows lawmakers to intervene on behalf of constituents in ways not possible with externality taxation (Schoenbrod, 1993); and
- Political preferences about the "right" degree of pollution for this or that substance or protecting the public health regardless of cost are more compelling to voters, and thus lawmakers, than market preferences.

Given that current law relies upon regulation rather than taxation to address the external costs of energy consumption, do external costs remain even after the effects of environmental regulation are taken into account? Figure 6.1 suggests that it is impossible to answer that question satisfactorily. But if one accepts EPA's assessment of human health risks from pollution as a starting point, Harvard law professor W. Kipp Viscusi concludes that no unpriced environmental externalities exist from natural gas or oil consumption, but that some unpriced environmental externalities arise from coal consumption (Viscusi et al., 1994).[16]

A more recent assessment by economists Ian Parry and Kenneth Small considers only the externalities associated with gasoline consumption

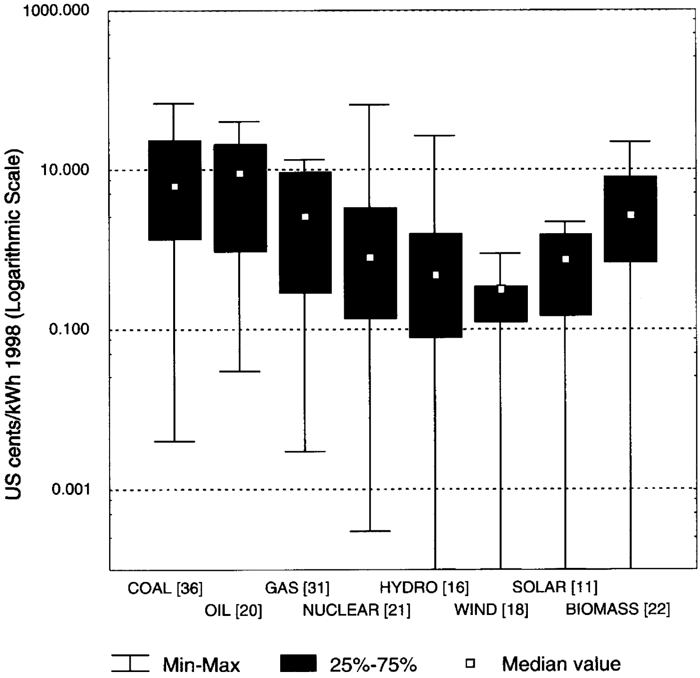

Figure 6.1. Range of external costs estimates (Adapted from Sundqvist and Soderholm, 2002, p. 19)

(Parry and Small, 2005, Table 1). Their review of the literature concludes that the optimal *second-best* gasoline tax in the United States would be \$1.01 per gallon.[17] That \$1.01 per gallon figure is broken down as follows: 16 cents to pay for cost of conventional pollution; 5 cents to pay for the costs of greenhouse gas emissions; 30 cents to pay for the costs associated with traffic congestion; and 24 cents to pay for costs associated with traffic accidents.

Ideally, however, the costs associated with traffic congestion are internalized by tolls that vary depending upon roadway congestion.[18] The costs associated with traffic accidents are also best internalized by automobile insurance premiums. Gasoline taxes are a rather imperfect means to address those externalities because, in the first case, they are imposed regardless of whether the motorist is contributing to congestion and, in the latter case, regardless of the propensity to cause accidents or indemnify injured parties.

Accordingly, Parry and Small's study (2005) suggests that a "first-best" gasoline tax would address externalities that total 25 cents per gallon – the sum of the environmental damages caused by gasoline consumption.[19] Current gasoline taxes in the United States, however, average 38 cents per gallon, which suggests that the environmental externality associated with gasoline is internalized by existing taxes.[20]

One might recall, however, that gasoline taxes in the United States are designed as user fees to pay for road construction and maintenance. This suggests that the 25 cent environmental externality tax would properly be an addition to the current levy. But current road construction and maintenance programs are incredibly inefficient, which means that the gasoline tax is almost certainly "too high" at present for passenger vehicles.[21]

There are two fundamental problems with the current regime. First, because pavement is typically laid far too thinly, maintenance costs are excessive. Second, even though trucks cause almost all the damage to existing roadways, they pay only about 29% of the maintenance costs through their fuel taxes and user fees (Small et al., 1989, p. 59). Accordingly, passenger vehicles pay far higher gasoline taxes than is warranted by efficient road design and operation.

Efficient road charges would not have any fuel taxes at all. Instead, roads would be paid for with road-use damage charges and congestion charges. Such charges would induce investment in thicker roads and multi-axle trucks. Because damage is the result not of gross weight but weight per axle, efficient charges on a fully loaded 5-axle intercity semi-trailer would be less than two-thirds of their current charges, but charges on 33,000 pound two-axle delivery truck would triple (Small et al., 1989, p. 117).

The upshot is that the internalization of environmental costs related to gasoline consumption would increase the price of gasoline relative to the current tax, but not by the full 25 cents per gallon calculated by Parry and Small (2005). In addition, because emissions in Los Angeles, for example, have a far greater environmental impact – and thus, far greater monetary costs – than equivalent emissions in Sioux City, Iowa, a gasoline tax designed at the national level will almost certainly be "wrong" all the time – too high in rural areas and too low in urban areas.

A perfectly efficient gasoline tax, then, would (1) be levied by local governments, not by the federal government; (2) be largely about internalizing environmental externalities, not internalizing congestion or road construction and maintenance costs (which should be addressed by different charges, fees, and funding mechanisms). Environmental externalities certainly exist, but it's unclear to what extent gasoline prices are "too low" as a consequence. All we can say is that gasoline prices are likely "too high" in some areas and for some consumers and "too low" in other areas and for other consumers. Raising gasoline prices via an environment externality tax at the federal level would therefore not necessarily improve economic efficiency.

6.5. GOVERNMENT INTERVENTION AND PRICES

Many politicians and policy activists argue that government interference in energy markets is so extensive that energy prices are political constructs. Accordingly, leaving energy decisions to market actors – guided as they are by defective, politically created price signals – will not produce efficient outcomes.

While one might expect this argument to be made by those who favor reduced government intervention in energy markets, the opposite is true. This argument is generally employed by those who support even greater involvement in energy markets. Only by more extensive (and presumably, better) government intervention can energy markets be made more efficient.

The most obvious problem with this argument is that it assumes that the political dynamics that have led to inefficient policies in the past (interventions provide concentrated benefits to some but diffuse costs to a larger group of "others") will end. Such wishful thinking has no theoretical or empirical basis. A more defensible argument calls for elimination of laws and regulations that distort energy prices.

A second problem is that the argument overstates the extent and effect of subsidies in energy markets. According to the Energy Information Administration (EIA, 2000), energy subsidies only amounted to $6.2 billion in 1999, or 1% of total energy expenditures, although other analysts have argued that EIA's estimates are too low.[22] While that estimate pre-dates passage of the Energy Policy Act of 2005, the expanded interventions contained in that Act were expected to cost the treasury $14.6 billion over 10 years – not enough to substantially alter EIA's 1999 finding that energy subsidies were very small in terms of the overall size of the energy economy.

For our purposes, however, the size of the subsidies is less important than the nature of the subsidies. Subsidies that do not affect marginal costs of production cannot affect market prices. Taxpayers are poorer and owners of subsidized companies are richer, but as long as marginal costs are not altered, prices are not altered, and efficiency is unaffected.

Even if marginal costs of some producers are altered, market prices may not be affected. Subsidies to the nuclear and renewable energy industries may reduce their respective marginal costs, but both nuclear and renewable energy generators are typically infra-marginal supply sources.[23] So those subsidies – however objectionable – do not affect prices and thus final demand for electricity.[24]

Regulatory interventions affect prices far more dramatically than do tax preferences or subsidies. A good example is the ethanol production mandate in the 2005 Energy Policy Act, which requires gasoline to contain 4 billion gallons of ethanol in 2006 and more thereafter. This mandate clearly affects retail fuel prices,[25] but a detailed assessment of costs and benefits is very hard to construct.[26] Despite the difficulties involved in quantifying costs, the EIA believes that:

> It is regulation and not subsidization that has the greatest impact on energy markets... The economic impact of just those energy regulatory programs considered in this [pre-1992 Energy Policy Act] report total at least 5 times that amount [of direct fiscal subsidy].
>
> (EIA, 1992)[27]

Three regulatory interventions are thought to be responsible for the bulk of the price distortions. First, the government uses tax dollars to ensure that domestic markets have safe, reliable, and low-cost access to foreign oil and gas, but those public expenditures are not reflected in the cost of imported energy. Second, government policies abroad restrict oil and gas production and thus produce prices that are "too high" given underlying geological realities and global market demand. Third, retail electricity prices are regulated by the state and regulated prices deviate from market prices.

6.5.1 National Security Costs of Energy

Quantifying the national security costs associated with energy consumption is difficult. The Institute for the Analysis of Global Security (2004), for instance, estimated that the current price of securing American access to Middle East oil was more than $50 billion annually. Greenpeace says those costs are substantially less; between $12 billion and $26.7 billion a year (Koplow and Martin, 1998).[28] The Congressional Research Service, on the other hand, says they are only $500 million a year (Congressional Research Service, 1992). None of those estimates, of course, include the cost of "Operation Iraqi Freedom," which may or may not have an oil mission component attached thereto (Taylor, 2003).

Agreement about national security externalities is hard to reach because military and foreign policy expenditures are generally tasked with multiple missions and objectives, and oil security is simply one mission of many. Analysts disagree about how to divide those missions into budgetary terms.

Debate about the size of the U.S. military's "oil mission" and related foreign policy expenses is interesting but not particularly relevant to a conversation about energy prices. From an economic perspective, the key question is whether an elimination of U.S. military and foreign aid expenditures dedicated to "the oil mission" would result in an increase in the price of oil, and, if so, how much? That is the true measure of the national security externality if it exists. Measuring the externality by the amount of money government spends on the oil mission is at best a measure of how much politicians *believe* the externality might be. Political assessments may or may not be accurate.

To be sure, if the termination of the American "oil mission" implied the termination of all military, police, and court services in the region, petroleum extraction investments would become more risky and oil from that region presumably more expensive. But remember that oil companies in the region are creatures of government. So the question is really whether Middle-East governments would produce less oil because the United States ended its oil-related military mission and foreign aid. Or would oil producing states provide – or pay others to provide – military services to replace those previously provided by the United States?

We believe that a cessation of U.S. security assistance would be replaced by security expenditures from other parties. First, oil producers will provide for their own security needs as long as the cost of doing so results in greater profits than equivalent investments could yield. Because Middle-Eastern governments typically have nothing of value to trade except oil, they must secure and sell oil to remain viable. Second, given that their economies are so heavily dependent upon oil revenues, Middle-Eastern governments have even more incentive than we do to worry about the security of production facilities, ports, and sea lanes. Third, even if producing countries provide inadequate security in the eyes of consuming countries, consuming countries can pay producers to augment it.

In short, whatever security our presence provides (and many analysts think that our presence actually *reduces* security) could be provided by other parties were the United States to withdraw (Jervis, 2005). The fact that the Saudi Arabia and Kuwait paid for 55% of the cost of Operation Dessert Storm suggests that keeping the Straights of Hormuz free of trouble is certainly within their means.[29] The same argument applies to Al Qaeda threats to oil production facilities.

If oil regimes paid for their own military protection and the protection of their own shipping lanes, would U.S. Middle-East military expenditures really go down? The answer might very well be "no" for two very different reasons. First, the U.S. Middle-East military presence stems from our implicit commitment to defend Israel as well as the region from Islamic fundamentalism, and those missions would not likely end simply because Arab oil regimes paid for their own economic security needs. Second, bureaucratic and congressional inertia might leave military expenditures constant regardless of Israeli or petroleum defense needs because of the pork barrel aspects of defense expenditures. In this admittedly cynical view, military expenditures are undertaken not just to enhance security, but also to provide jobs and economic wellbeing in congressional districts.

Thus, U.S. Persian Gulf expenditures should not be viewed as a subsidy that lowers oil prices below what they otherwise would be. Instead, the expenditures should be thought of as a taxpayer financed gift to oil regimes and the Israeli government. The gift has no effect on oil prices.

6.5.2 Government Interference in Oil Production

Many politicians and policy advocates argue that it's absurd to talk about free energy markets in a world in which the OPEC cartel restricts oil supply (EIA, 2006, pp. 25–35). The economics literature is divided on the issue of OPEC's influence on world crude oil prices.[30] Francisco Parra, a former Secretary-General of the OPEC cartel, believes that production costs are so low in the Persian Gulf and the reserves there are so large that world crude oil prices would average under $5.00 per barrel if countries did not collude to restrain output (Parra, 2004, p. 337). Other economists believe that only Saudi Arabia restricts output while the other countries produce as much as they can (Alhajji and Huettner, 2000, pp. 31–60). Still others argue that producer states did not constrain supply from 1974 to 1980 and, accordingly, may not be doing so now (Loderer, 1985).

Even if OPEC or Saudi Arabia restrict output, markets do allocate the oil that is produced efficiently among consumers. And if producers aren't producing as much as they might, the consequence is higher rather than lower than appropriate gas prices, the opposite of the goal of those who make externality arguments.

If the federal government were to set about "correcting" that problem, what might it do? It could compel production, but it's hard to imagine how the United States could reasonably compel Venezuela, Saudi Arabia, Iran, or Russia to increase production. It could subsidize domestic production, but that would lead to additional inefficiency and misallocation of capital. It could lower prices to consumers, but that would force prices to tell a story that reflected political wishes rather than economic reality. Such interventions have not worked well in the past (Taylor and Van Doren, 2006).

OPEC behavior may result in oil and gasoline prices that are much higher than if production decisions were made by private companies. But practical remedies are hard to imagine. And all would reduce rather than increase the price of oil.

6.5.3 Inefficient Electricity Regulation

Retail electricity prices – for most consumers, at most times, and in most places – are dictated by government regulation. Prices in wholesale markets are the product of market forces, but those prices are only indirectly and partially reflected in retail rates.

Retail electricity prices are "wrong" all the time because they do not vary to reflect supply and demand fundamentals. They are backwards looking cost-recovery mechanisms rather than forward looking resource-allocation devices. Prices are too high during off-peak and too low during peak consumption hours. Regulation also frequently requires some user groups pay higher prices so that others can pay lower prices (a phenomenon economists describe as "cross-subsidy").

The remedy according to most economists is "real-time pricing;" retail electricity prices would reflect minute-by-minute changes in supply and demand (Faruqui et al., 2001). Based on the California Demand Response experiment, Pacific Gas and Electric has estimated that real-time pricing would yield a savings in present value of $338 million (Faruqui and Earle, 2006, p. 27). The bulk of the savings from the installation of advanced meters, however, does not arise from the demand response but the reduction in meter reading costs ($2 billion in present value) that is possible with advanced meters (Faruqui and Earle, 2006, p. 26).

The lesson is that real-time pricing does not have to be mandated. If it really saves money then utilities will adopt it voluntarily. The remedy to this problem is to simply free retail prices from political regulation.

6.6. CONCLUSIONS

Energy is like any other commodity in the marketplace, and there is little reason to believe that energy decisions cannot be directed efficiently by market price signals. The proper corrective for price distortions is not to give up reliance on prices but to eliminate the policies that cause the distortions. That implies internalizing externalities, to the extent possible, and eliminating government interventions that send incorrect signals to producers and consumers about energy supply and demand.

Happily, concerns that energy prices are substantially "wrong" in the United States today are overblown. Energy prices are reasonable reflections of total producer costs and consumer demand. There are certainly exceptions to this rule. For example, most renewable energy and nuclear power facilities would disappear without government support (Taylor and Van Doren, 2001, 2002; Heyes, 2002–2003). And there are easy correctives for policy makers to employ should government decide to end those price distortions.

Most government interventions in energy markets, however, are undertaken for distributional rather than efficiency concerns. Neither firms nor consumers like energy markets and politicians are willing to accommodate that dislike.

While this chapter has not addressed the case for intervention on equity grounds, it argues that efficiency-based arguments for intervention – which are often employed as rationales for intervention actually driven primarily by equity concerns – have little intellectual support. Our advice to those concerned with equity is to address those concerns outside of the context of energy markets and in a manner that distorts price information the least.

NOTES

[1] For a review of the literature, see Tyler Cowen (1988) and Charles Wolf (1991). We will not discuss so-called "equity" programs designed to assist low income people with their energy bills.

[2] For representative arguments, see Fisher and Rothkopf (1989) and Lovins and Lotspeich (1999).

[3] Three issues not discussed are the problem of "capture" in petroleum reservoirs, vertical integration in the oil industry, and natural monopoly issues in oil and gas pipelines. The problem of capture is of historical rather than current significance, and the other two leads to higher rather than lower than efficient oil prices, the opposite of current policy concern.

[4] Recoverable oil deposits within heavy bitumen in the Venezuelan Orinoco Belt may be nearly equal to Saudi proved reserves (Forero, 2006, p. C1). Shale rock in the United States are estimated to harbor three times the amount of petroleum found in proved Saudi reserves (Bartis et al., 2005). For an overview of unconventional petroleum resources, see Robert L. Bradley and Richard Fulmer (2004).

[5] For a review of the literature, see Robert Arnott (2002). For a withering critique of worries about near-term depletion of Saudi oil reserves, see Michael Lynch (2006)

[6] Empirical studies of petroleum markets suggest that, in the short run, a 10 percent increase in petroleum prices will reduce petroleum consumption by somewhere between 1% and four-tenths of 1%. Studies examining the relationship between changes in price and petroleum supply report that a 10 percent increase in petroleum prices will increase petroleum supplies in the short run by six-tenths of 1% (Lynch, forthcoming). Also Timothy Considine (2004, pp. 21–22). Empirical studies of consumer response in electricity markets are similar. In the short run, a 10% increase in electricity prices will reduce residential electricity consumption by somewhere between six-tenths of one percent to 5%; commercial electricity consumption by between 1.7 and 2.5%, and industrial electricity consumption by somewhere between four-tenths of 1 percent and 2.2% (Bohi, 1981). A recent study of price response based on 119 customers from New York State falls within this range; specifically, the surveyed customers had an average price elasticity of 0.11, which means that their combined ratio of peak to off-peak electricity usage declined by 11% in response to a doubling of peak prices (relative to off-peak prices) (Goldman et al., 2005). For a recent update on residential elasticities (–065 to –095) from the California demand response experiment see Ahmad Faruqui and Robert Earle (2006, p. 26)

[7] The price increases of the 1970s, for example, were followed by a dramatic reduction in real oil prices after 1985. In 1981, the average price paid by U.S. refineries for crude oil was $53.74 in constant (2000) dollars. In 1986, the average price paid was $17.56 in constant (2000) dollars (EIA, 2005). Economists estimate that every 1% increase in oil prices results in a 1 percent decrease in oil consumption in the long run (Pindyck, 1979; Adelman, 1995).

[8] For a non-technical discussion, see Surowiecki (2005). For a more comprehensive treatment, see Donald Jones et al., (2004) and Robert Barsky and Lutz Kilian (2004).

[9] For representative arguments, see Hirst and Brown (1990) and Brown (2001).

[10] Although the principle-agent problem receives a great deal of attention in the literature, we don't find it to be a market failure even in theory. If renters wanted energy efficient appliances, they would

manifest that desire by favoring rental properties with energy efficient appliances, providing all the incentive necessary for landlords to take renter preferences into account.

[11] Some studies – most notably Meyers et al. (2003) – find substantial net savings from those programs. Sutherland argues that those studies (i) overestimate energy savings due to the regulations because much of those gains would have occurred endogenously in markets, and (ii) employ artificially low discount rates and should instead use the discount rates observed in the appliance market.

[12] Most of the literature reports net savings from the programs negatively evaluated by Loughran and Kulick. For a representative example of this literature, see Brown and Mihlmester (1995). Those studies, however, typically rely heavily on data and reports from the utilities themselves regarding program success (Brown and Mihlmester, for instance, rely totally on such studies and accept their findings at face value). Unfortunately, the methodologies employed by utility-sponsored reports vary a great deal, so meta-analysis is impossible. Regardless, a close reading of the utility-sponsored reports reveals that they are typically rife with serious analytical errors – such as relying on engineering estimates of energy savings rather than observed changes in energy consumption (which ignores possible "rebound effects" induced by reductions in the marginal cost of electricity services), insufficient controls for "free riders" (economic jargon for those who would have invested in energy efficiency even without the program) and lack of attention to moral hazard problems (for instance, the fact that consumers might put-off private energy efficiency investments in hopes of gaining subsidy from utility-sponsored programs at some later date) – and those errors are rarely corrected in secondary studies (Wirl, 1997, pp. 119–142; Loughran and Kulick, 2004, pp. 22–25). Moreover, few of the studies in the literature that rely on the data reported by the utilities acknowledge that the utilities have both the means and motive to favor programs that lead to less – not more – conservation and to inflate reported net benefits. Instead, they tend to accept utility reported data and analysis at face value (Wirl, 2000, pp. 173–183). What distinguishes Loughran and Kulick's study from the rest is that the authors reach outside of the utility-sponsored studies to ascertain whether utility-sponsored energy conservation programs actually reduce energy intensity once all other variables are controlled for and, if so, at what cost.

[13] This argument was first and most forcefully made by A.C. Pigou (1920). Later, many economists came to believe that pollution taxes have an additional benefit besides improving the environment: the revenue from pollution taxes can replace revenue from existing, more distortionary taxes, thus reducing the deadweight losses from those taxes (Tullock, 1967). Accordingly, many economists believe that optimal externality taxes are somewhat greater than what a simple calculation of negative externality costs might otherwise suggest. Sarah West and Roberton Williams (2004), for example, argue that an optimal externality tax should be about 35% higher than marginal external damages. Other economists believe that pollution taxes compound the distortions caused by other preexisting taxes.

[14] Some economists have argued that if government were to acknowledge and enforce private property rights over environmental resources, most environmental regulations would be unnecessary and that the resulting legal regime would be more efficient than the current regulatory regime (Rothbard, 1982). Most economists, however, believe that the costs associated with policing private environmental rights ("transaction costs" in economic parlance) are so steep that a legal regime of that sort would be unworkable (Coase, 1960).

[15] Weitzman demonstrated that uncertainty about pollution quantities and certainty about pollution abatement costs is optimal when the marginal benefits of additional pollution control are low and the marginal costs of additional abatement are high – the stylized facts for "normal" pollutants. Certainty about exposure or emissions and uncertainty about costs is optimal when the opposite is true – marginal benefits of pollution abatement are high relative to marginal costs – the stylized facts for very "toxic" pollution (Milliman, 1982).

[16] The authors did not consider the costs associated with global warming.

[17] The tax is second-best because it taxes gasoline rather than the directly offending behavior (emissions, congestion, and accidents).

[18] Variable toll congestion pricing now exists in state route 91 in Orange County California, I-15 in San Diego, I-394 in Minneapolis, and I-25 in Denver (Egan, 2005). For a discussion of optimal congestion pricing see Small et al., (1989; 2006).

[19] A true first-best tax would be on actual emissions. In addition, 26 cents of the $1.01 second best tax is described as a “Ramsey” tax arising from the correct observation that efficient taxes are higher on goods whose demand and supply are less elastic (gasoline) and less on goods whose demand and supply are more elastic (labor). If total spending could be kept constant and gas taxes increased and taxes on labor decreased, we agree.

[20] The figure is a weighted average of existing state taxes plus the federal fuels tax (U.S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information, 2005).

[21] Another complication is that a portion of the gasoline tax is diverted to transit and other programs. In 2003 $21 billion was diverted to transit. But highway user fees were less than highway expenditures by $36 billion resulting in a net subsidy of roads by general taxpayers (O’Toole, 2005).

[22] Douglas Koplow and John Dernbach (2001) argue that EIA did not accurately account for a number of direct energy subsidies and was wrong to “exclude provisions on the basis that they were available to more than just the energy sector, did not therefore constitute subsidies solely to energy, and were therefore beyond the research mandate they had been given” (Koplow, 2006).

[23] Natural gas-fired electricity is the marginal source of electricity at most times and places and thus the cost of gas-fired electricity establishes wholesale electricity prices for all electricity sources during most periods. The EIA finds that subsidies to the natural gas industry are negligible. In the transportation sector, the only industry worth examining is the oil industry, and subsidies to oil companies are both negligible and irrelevant to marginal production costs (Sutherland, 2001).

[24] States that regulate retail electricity rates based on a weighted average of the production costs from all electricity generation will indeed produce lower rates as a consequence of those subsidies. But that pricing methodology introduces more inefficiencies than are introduced by the subsidies themselves: unregulated markets do not work that way.

[25] Industry analysts in the spring of 2006 believe that the ethanol mandate in the 2005 Energy Policy Act increased gasoline prices by between 8–60 cents per gallon (McKay, 2006).

[26] The most ambitious attempt to account for all energy subsidies in the United States can be found in Douglas Koplow’s (2004), “Federal Subsidies for Energy in 2003 – A First Look.” Koplow estimates that energy subsidies in the United States (to the extent to which they can be quantified) range from $37–64 billion annually, but only $25–37 billion if national defense costs associated with protecting Persian Gulf oil shipments are subtracted out of the total (as they probably should be). Koplow’s calculations thus comport well with EIA’s estimate that regulatory interventions are about 5 times as significant as direct tax subsidies.

[27] The EIA’s 1999 report on energy subsidies – which updated the 1992 report – unfortunately ignored regulatory subsidies (EIA, 2000).

[28] 1998 published estimate updated by Koplow and Martin to 2003 dollars.

[29] Saudi Arabia and Kuwait paid approximately $33 billion (55%) toward the total cost of Desert Storm and Desert Shield, which was $60 billion. The U.S. share was only $6 billion (10%). Defense Department press release 125-M, May 5, 1992.

[30] For an orthodox answer to the question and a good literature review on the subject, see James Smith (2005).

REFERENCES

Adelman, M.A.: 1995, *The Genie Out of the Bottle*, MIT Press, Cambridge, MA, USA, p. 190.

Alhajji, A.F. and Huettner, David: 2000, “OPEC and World Crude Oil Markets from 1973 to 1994: Cartel, Oligopoly or Competitive?” *Energy Journal* 21:3, pp. 31–60.

Arnott, Robert: 2002, “Supply Side Aspects of Depletion,” *Journal of Energy Literature* 8:1, pp. 3–21.

Ballonoff, Paul: 1999, “On the Failure of Market Failure,” *Regulation* 22:2, pp. 17–19.

Barresi, Paul: 1997, “Beyond Fairness to Future Generations: An Intergenerational Alternative to Intergenerational Equity in the International Environmental Arena,” *Tulane Environmental Law Journal* 11:1, pp. 59–88.

Barsky, Robert and Kilian, Lutz: 2004, "Oil and the Macroeconomy Since the 1970s," National Bureau of Economic Research, Working Paper 10855, [online] www.nber.org/papers/w10855, accessed July 2006.

Bartis, James, LaTourrette, Tom, Dixon, Lloyd, Peterson, D.J., and Cecchine, Gary: 2005, *Oil Shale Development in the United States: Prospects and Policy Issues*, Rand Corporation, Santa Monica, CA, USA.

Bernanke, Ben, Gertler, Mark, and Watson, Mark: 1997, "Systematic Monetary Policy and U.S. Aggregate Economic Activity," *Brookings Papers on Economic Activity* 1, pp. 91–142.

Bohi, Douglas: 1981, *Analyzing Demand Behavior: A Survey of Energy Elasticities*, Johns Hopkins University Press, Baltimore, MD, USA.

Bradley, Robert L. and Fulmer, Richard: 2004, *Energy: The Master Resource*, Kendall/Hunt, Dubuque, IA, USA.

Brown, Marilyn: 2001, "Market Failures and Barriers as a Basis for Clean Energy Policies," *Energy Policy* 29:14, pp. 1197–1207.

Brown, Marilyn and Mihlmester, Philip: 1995, "Actual Vs. Anticipated Savings from DSM Programs: An Assessment of the California Experience," International Energy Program Evaluation Conference, *Proceedings of the 1995 International Energy Program Evaluation Conference*, Chicago, IL, USA, pp. 295–301.

Coase, Ronald: 1960, "The Problem of Social Cost," *Journal of Law and Economics* 3, pp. 1–44.

Congressional Research Service: 1992, "The External Costs of Oil Used in Transportation," CRS Report for Congress, 92–574ENR, Washington, DC, USA.

Considine, Timothy: 2004, "A Short-Run Model of the World Crude Oil Market," Pennsylvania State University, Department of Energy and Geo-Environmental Engineering Working Paper, pp. 21–22.

Cowen, Tyler (ed.): 1988, *The Theory of Market Failure: A Critical Examination*, George Mason University Press, Fairfax, VA, USA.

Deffeyes, Kenneth: 2005, *Beyond Oil: The View from Hubbert's Peak*, Hill & Wang, New York, NY, USA.

Dixit, Avinash and Pindyck, Robert: 1994, *Investment under Uncertainty*, Princeton University Press, Princeton, NJ, USA.

Egan, Timothy: 2005, "Paying on the Highway to Get Out of First Gear," *New York Times*, April 28, p. A1.

[EPRI] Electric Power Research Institute: 1993, *1992 Survey of Utility Demand-Side Management Programs*, Vols. 1 and 2, EPRI TR-102193, EPRI, Palo Alto, CA, USA.

Espey, Molly: 2005, "Do Consumers Value Fuel Economy?" *Regulation* 28:4, Winter 2005–2006, pp. 8–10.

Faruqui, Ahmad and Earle, Robert: 2006, "Demand Response and Advanced Metering," *Regulation* 29:1, pp. 24–27.

Faruqui, Ahmad, Chao, Hung-po, Niemeyer, Victor, Platt, Jeremy, and Stahlkopf, Karl: 2001, "Getting Out Of The Dark," *Regulation* 24:3, pp. 58–62.

Fickett, Arnold, Gellings, Clark, and Lovins, Amory: 1990, "Efficient Use of Electricity," *Scientific American*, pp. 65–74.

Fisher, Anthony and Rothkopf, Michael: 1989, "Market Failure and Energy Policy", *Energy Policy* 17:4, pp. 397–406.

Forero, Juan: 2006, "For Venezuela, A Treasure in Oil Sludge," *New York Times*, June 1, 2006, p. C1.

Goldman, C., Hopper, N., Bharvirkar, R., Neenan, B., Boisvert, R., Cappers, P., Pratt, D., and Butkins, K.: 2005, *Customer Strategies for Responding to Day-Ahead Market Hourly Electricity Pricing*, LBNL-57128, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Hamilton, James and Herrera, Anna Maria: 2004, "Oil Shocks and Aggregate Macroeconomic Behavior," *Journal of Money, Credit, and Banking* 36:2, pp. 265–286.

Hassett, Kevin and Metcalf, Gilbert: 1993, "Energy Conservation Investment: Do Consumers Discount the Future Correctly?" *Energy Policy* 21:6, pp. 710–716.

Heyes, Anthony: 2002–2003, "Determining the Price of Price-Anderson," *Regulation* 25:4, pp. 26–30.

Hirsch, Robert, Bezdek, Roger, and Wendling, Robert: 2005, "Peaking of World Oil Production: Impacts, Mitigation, and Risk Management," Report Commissioned by the U.S. Department of Energy, [online] http://www.hilltoplancers.org/stories/hirsch0502.pdf, accessed July 2006.

Hirst, Eric and Brown, Marilyn: 1990, "Closing the Energy Efficiency Gap: Barriers to the Efficient Use of Energy" Resources," *Conservation and Recycling* 3, pp. 267–281.

Institute for the Analysis of Global Security: 2005, *The Real Cost of Oil: How Much are We Paying for a Gallon of Gas?* [online] http://www.iags.org/costofoil.html, accessed May 2005.

Jaffe, Adam and Stavins, Robert: 1994, "The Energy-Efficiency Gap: What Does it Mean?" *Energy Policy* 22:10, pp. 804–810.

Jervis, Robert: 2005, "Why the Bush Doctrine Cannot Be Sustained," *Political Science Quarterly* 120:3, pp. 351–377.

Johnson, Ruth and Kaserman, David: 1983, "Housing Market Capitalization of Energy-Saving Durable Good Investments," *Economic Inquiry* 21, pp. 374–386.

Jones, Donald, Leiby, Paul, and Paik, Inja: 2004, "Oil Shocks and the Macroeconomy: What Has Been Learned Since 1996," *Energy Journal* 25:2, pp. 1–32.

Kalt, Joseph: 1981, *The Economics and Politics of Oil Price Regulation*, MIT Press, Cambridge, MA, USA.

Koomey, Jonathan, Sanstad, Alan, and Shown, Leslie: 1995 "Magnetic Fluorescent Ballasts: Market Data, Market Interventions, and Policy Success," LBL-37702, Lawrence Berkeley Laboratory, Berkeley, CA.

Koplow, Douglas: 2006, "Problems with Federal Subsidy Estimates Generated by the US Energy Information Administration," Earth Track, [online] http://earthtrack.net/earthtrack/index.asp?page_id=201&catid=73, accessed February 2006.

Koplow, Douglas: 2004, "Federal Subsidies for Energy in 2003 – A First Look," in National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges*, Technical Appendix, Washington, DC, USA, pp. 204–218.

Koplow, Douglas and Dernbach, John: 2001, "Federal Fossil Fuel Subsidies and Greenhouse Gas Emissions: A Case Study of Increasing Transparency for Fiscal Policy," *Annual Review of Energy and the Environment* 26, pp. 361–389.

Koplow, Douglas and Martin, Aaron: 1998, "Fueling Global Warming: Federal Subsidies to Oil in the United States," Greenpeace, Washington, DC, USA.

Landsburg, Steven: 1997, "Tax the Knickers Off Your Grandchildren," *Slate*, [online] http://www.slate.com/id/2036/, accessed July 2006.

Loderer, Claudio: 1985, "A Test of the OPEC Cartel Hypothesis: 1974–1983," *Journal of Finance* 40:3, pp. 991–1006.

Loughran, David and Kulick, Jonathan: 2004, "Demand-Side Management and Energy Efficiency in the United States," *Energy Journal* 25:1, pp. 19–44.

Lovins, Amory and Lotspeich, Chris: 1999, "Energy Surprises for the 21st Century." *Journal of International Affairs* 53:1, pp. 191–208.

Lynch, Michael: 2006, "Crop Circles in the Dessert: The Strange Controversy Over Saudi Oil Production," International Research Center for Energy and Economic Development, Occasional Paper 40, Boulder, CO, USA.

Lynch, Michael: forthcoming, "Effect on a Major Disruption of Persian Gulf Oil on the Oil Market," Cato Institute, Washington, DC, USA.

Metcalf, Gilbert: 1994, "Economics and Rational Conservation Policy," *Energy Policy* 22, pp. 819–825.

Metcalf, Gilbert and Rosenthal, Donald: 1995, "The 'New' View of Investment Decisions and Public policy Analysis: An Application of Green Lights and Cold Refrigerators," *Journal of Policy Analysis and Management* 14:4, pp. 517–531.

Meyers, S., McMahon, J.E., McNeil, M., and Liu, X.: 2003, "Impacts of U.S. federal energy efficiency standards for residential appliances,"*Energy* 28: pp. 755–767.

Milliman, Jerome: 1982, "Can Water Pollution Policy Be Efficient?" *Cato Journal* 2:1, Spring, pp. 165–196, particularly pp. 179–184.

McKay, Peter: 2006, “Demand for Ethanol Aggravates Pain at the Pump,” *Wall Street Journal*, June 19, p. C4.

Nichols, Albert: 1992, “How Well Do Market Failures Support the Need for Demand Side Management?” National Economic Research Associates, Cambridge, MA, USA, pp. 22–25.

O’Toole, Randal: 2005, “Vanishing Automobile Update #54,” May 15, [online] http://ti.org/vaupdate54.html, accessed July 2006.

Parra, Francisco: 2004, *Oil Politics: A Modern History of Petroleum*, I.B. Tauris, New York, NY, USA.

Parry, Ian W.H., and Small, Kenneth A.: 2005, “Does Britain or the United States Have the Right Gasoline Tax?” *American Economic Review* 95:4, pp. 1276–1289.

Pigou, A.C.: 1920, *The Economics of Welfare*, Macmillan, London, UK.

Pindyck, Robert: 1979, “Inter-Fuel Substitution and the Industrial Demand for Energy: An International Comparison,” *Review of Economics and Statistics*, May, pp. 169–179.

Rothbard, Murray: 1982, “Law, Pollution Rights, and Air Pollution,” *Cato Journal* 2:1, Spring, pp. 55–99.

Schoenbrod, David: 1993, *Power Without Responsibility: How Congress Abuses the People Through Delegation*, Yale University Press, New Haven, CT, USA.

Simmons, Matthew: 2005, *Twilight in the Dessert: The Coming Saudi Oil Shock and the World Economy*, Wiley, Indianapolis, IN, USA.

Small, Kenneth, Winston, Clifford, and Evans, Carol: 1989, *Road Work*, Brookings, Washington, DC, USA.

Small, Kenneth, Clifford, Winston, and Jia, Yan: 2006, “Differentiated Road Pricing, Express Lanes, and Carpools: Exploiting Heterogenous Preferences in Policy Design” AEI-Brookings Joint Center Working Paper 06-06-02, [online] SSRN: http://ssrn.com/abstract=893163, accessed July 2006.

Smith, James: 2005, “Inscrutable OPEC? Behavioral Tests of the Cartel Hypothesis,” *Energy Journal* 26:1, pp. 51–82.

Sundqvist, Thomas and Soderholm, Patrik: 2002, “Valuing the Environmental Impacts of Electricity Generation: A Critical Survey,” *Journal of Energy Literature* 8:2, pp. 3–41.

Surowiecki, James: 2005, “Oil Change,” *The New Yorker*, May 2, p. 46.

Sutherland, Ronald: 2003, “The High Costs of Federal Energy Efficiency Standards for Residential Appliances,” Policy Analysis 504, Cato Institute, Washington, DC, USA, pp. 8–12.

Sutherland, Ronald: 2001, “ ‘Big Oil’ at the Public Trough? An Examination of Petroleum Subsidies,” Policy Analysis 390, Cato Institute, Washington, DC, USA.

Taylor, Jerry: 2003, “Blood for Oil?” Cato Commentary, Cato Institute, Washington, DC, March 18, [online] http://www.cato.org/pub_display.php?pub_id=3029, accessed July 2006.

Taylor, Jerry and Van Doren, Peter: 2006, “Economic Amnesia: The Case against Oil Price Controls and Windfall Profit Taxes,” Policy Analysis 561, Cato Institute, Washington, DC, USA.

Taylor, Jerry and Van Doren, Peter: 2005, “The Case Against the Strategic Petroleum Reserve,” Policy Analysis 555, Cato Institute, Washington, DC, USA.

Taylor, Jerry and Van Doren, Peter: 2002, “Evaluating the Case for Renewable Energy: Is Government Support Warranted,” Policy Analysis 422, Cato Institute, Washington, DC, USA.

Taylor, Jerry and Van Doren, Peter: 2001, “Nuclear Power Play,” *Washington Post*, May 18.

Togeby, Mikael and Larsen, Anders: 1995, “The Potential for Electricity Conservation in Industry: From Theory to Practice,” *Into the 21st Century: Harmonizing Energy Policy, Environment, and Sustainable Economic Growth*, Cleveland: International Association for Energy Economics, Cleveland, OH, USA, pp. 48–55.

Tullock, Gordon: 1997, “Excess Benefit,” *Water Resources Research* 3, pp. 643–644.

U.S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information: 2005, “Monthly Motor Fuel Reported by States,” April, p. 13; [online] www.fhwa.dot.gov/ohim/mmfr/apr05.pdf, accessed July 2006.

[EIA] U.S. Energy Information Administration: 1992, “Federal Energy Subsidies: Direct and Indirect Interventions in Energy Markets,” United States Department of Energy, Washington, DC, USA, p. x.

[EIA] U.S. Energy Information Administration: 2000, “Federal Intervention and Subsidies in Energy Markets 1999: Energy Transformation and End Use,” SR/OIAF/200–02, Washington, DC, USA, p. xi.

[EIA] U.S. Energy Information Administration: 2005, *Annual Energy Review 2004*, Table 5.18, Crude Oil Domestic First Purchase Prices, EIA, Washington, DC, [online] http://www.eia.doe.gov/emeu/aer/, accessed July 2006.

[EIA] U.S. Energy Information Administration: 2006, *International Energy Outlook 2006*, U.S. Department of Energy, Washington, DC, USA, pp. 25–35.

Van Doren, Peter: 1991, *Politics, Markets, and Policy Choices*, University of Michigan Press, Ann Arbor, MI, USA.

Viscusi, W. Kipp, Magat, Wesley A., Carlin, Alan, and Dreyfus, Mark K.P: 1994, "Environmentally Responsible Energy Pricing," *Energy Journal* 15:2, pp. 23–42.

Weiss, Edith: 1989, *In Fairness to Future Generations*, Transnational Publishers, Dobbs Ferry, NY, USA.

West, Sarah and Williams, Roberton: 2004, "Empirical Estimates for Environmental Policy Making in a Second-Best Setting," Working Paper 10330, National Bureau of Economic Research [online] http://papers.nber.org/papers/w10330, accessed July 2006.

Wirl, Franz: 1997, *The Economics of Conservation Programs*, Kluwer Academic Publishers, Norwell, MA, USA.

Wirl, Franz: 2000, "Lessons from Utility Conservation Programs," *Energy Journal* 21:1, pp. 87–108.

Weitzman, Martin: 1974, "Prices vs. Quantities," *Review of Economic Studies* 41, pp. 477–491.

Wolf, Charles: 1991, *Markets or Government: Choosing Between Imperfect Alternatives*, MIT Press, Cambridge, MA, USA.

World Energy Council: 2004, *Survey of Energy Resources*, World Energy Council, London.

CHAPTER 7

ENERGY MYTH SIX – THE BARRIERS TO NEW AND INNOVATIVE ENERGY TECHNOLOGIES ARE PRIMARILY TECHNICAL: THE CASE OF DISTRIBUTED GENERATION (DG)

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7.1. INTRODUCTION

For almost a century, the electric utility system had been well served by gigantic generating plants that delivered energy to customers through an intricate grid of power lines. But traditional generation technology appeared to reach limits to improvement by the 1970s, hindering companies' ability to lower the cost of power. Moreover, as consumption grew and as utility firms and independent generating companies put new demands on the grid, especially during the period of utility restructuring that began in the 1990s, the transmission and distribution network became constrained. Parts of the grid became unstable, leading to events such as the cascading Northeast blackout of 2003.

Advocates of distributed generation (DG) facilities have suggested a novel approach to the challenges facing the conventional network of power production, transmission, and distribution. Employing small, modular (and sometimes renewable-energy) generators that produce power close to end users, they foresee a host of potential benefits. In contrast to the customary use of a few large-scale generators distantly located from load centers, employment of numerous, but small plants can provide power onsite with little reliance on the distribution and transmission grid. DG technologies produce power in capacities that range from a fraction of a kilowatt (kW) to about 100 megawatts (MW); utility-scale generation units have capacities that sometimes reach beyond 1,000 MW. Distributed generators can also offer, in many cases, lower-cost electricity and higher power

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reliability and security with fewer environmental consequences when compared to traditional power generators.

Despite such potential benefits, DG technologies remain minimally utilized in the American electric utility system. To be fair, some of the criticisms are legitimate: DG technologies tend to have higher capital costs per installed kW than centralized stations; interconnecting DG technologies to the power grid can sometimes complicate system safety; and the intermittent and dispersed nature of DG technologies makes them more difficult to monitor and standardize. But the relative neglect of DG technologies occurs at least partly because opponents prefer to take a conservative approach – such as fixing problems within the century-old paradigm that relies on large-scale generation units and the transmission infrastructure. Perhaps more significantly, they criticize the new technologies by arguing that they are immature or technically inadequate.

For example, when evaluating the prospects of renewable-energy DG technologies, Brian O'Shaughnessy (2005, p. 68), president of an American manufacturing firm, told senators that "since the evolution of renewable power is at a very early stage in its development, mandating renewable power with today's technology is like trying to go to the moon in the 1950s." The Electric Power Research Institute's *Electricity Technology Roadmap* (2003, p. 3) concluded that technical problems relating to energy capture, storage, and manufacturing meant that "the market penetration of renewable technologies has been limited." A comprehensive Resources for the Future study of small-scale renewable energy systems further noted in 1999 that such technologies "have failed to emerge as a prominent component of the U.S. energy infrastructure" because of poor "technological performance" compared to "conventional technologies" (McVeigh et al., 1999, pp. i–ii).

Criticisms of other DG technologies, such as microturbines and small-scale gas-turbine generators, tend to focus primarily on technical issues such as poor fuel efficiency, limited power supply, and the untested nature of such systems. Thomas Petersik, a former analyst at the U.S. Energy Information Administration, argued that "distributed generation technologies experience much higher (in the neighborhood of 50%) capital costs per kilowatt, in part because they lack economies of scale; they are much less fuel efficient, and operations and maintenance are much more expensive" (Sovacool, 2006, p. 203). A 2004 *Energy Policy* article contended that "mini power plants" are still constrained by factors such as "limited power supply" and "low load factor" (Chaurey et al., 2004, p. 1694). William E. Liss (1999, p. 4), Director of the Gas Research Institute, suggested that "the market for small-scale power generation has not developed in the past two decades" because of "negative scaling effects" and "legitimate technical issues."

Denigration of DG technologies on grounds of perceived technical failure should not appear unusual. Actually, it continues a long trend among engineers (and historians too) who view technical problems as the primary reason for the failure of other nascent technologies. For example, most people who have evaluated electricity-powered automobiles of the early twentieth-century argue that their inability to thrive resulted simply from the lack of reliable batteries that could store enough energy for the vehicles (Rae, 1955; Flink, 1970, 1990; Graves et al., 1981). Yet other scholars have established that electric taxis and trucks used in a few cities demonstrated remarkable technical success. The revisionist academics suggest that the failure of electric automobile technology to flourish had more to do with an inadequate social and business infrastructure than with hardware deficiencies (Kirsch, 2000; Moms and Kirsch, 2001).

Similarly, after the Space Shuttle *Challenger* exploded in 1986, numerous investigations concluded that the cause of the accident was a circular seal made of rubber, known as an O-ring. In a televised press conference, the physicist Richard Feynman famously placed an O-ring in a glass of cold water to demonstrate such a seemingly uncomplicated technical failure. Others, however, have argued that the *Challenger* accident stemmed more from an overly rigid and hierarchical culture among managers of the National Aeronautics and Space Administration than from the deficiency of any individual piece of hardware (Collins and Pinch, 1998). In both cases, technical deficiency was used to explain otherwise socio-technical and institutional "failures."

To put such thinking in the context of contemporary American energy policy, this chapter addresses the myth that barriers to innovative energy technologies, such as distributed generation, are primarily technical. The chapter begins by examining the potential benefits of distributed generation technologies. Then, it explores government incentives for these technologies as a way to demonstrate how policymakers have attempted (perhaps not always wholeheartedly) to advance them. Next, we examine some of the demonstrable technical reasons for slow adoption of DG systems. The final part of the chapter, however, suggests that the success of the new technologies has been impeded by a host of social – not exclusively technical – factors. We find that a historical examination of the culture of electricity producers and users helps clarify why the new technologies have seen little use. Going beyond technical explanations (of alleged low efficiencies, limited capacity factors, etc.), we focus on the social nature of decision making among participants in the electric utility system. The approach not only helps us understand the reluctance to employ distributed generation technologies. It also suggests ways of overcoming the barriers faced by their advocates.

7.2. ADVANTAGES OF DISTRIBUTED GENERATION TECHNOLOGIES

In recent years, the design of small-scale renewable energy and DG technologies has significantly improved. Photovoltaic (solar) panels now constitute modular technologies and can be sized at almost any capacity (or stacked to achieve large capacities). Wheelersburg Elementary School in Ohio, for instance, operates a 1 kW solar panel on its roof that helps power the cafeteria (Chambers et al., 2001, pp. 248–249). On the other end of the spectrum, Arizona Public Service, an electric utility company, has installed about 5 MW of photovoltaic cells, often in large arrays (Kurtz and Lewandowski, 2004). Wind turbines, photovoltaic panels, and biomass plants can also work in conjunction with other energy systems – such as fuel cells or microturbines – to create hybrid applications that improve overall fuel efficiency and extend the amount of time that the systems provide power independent from the grid (Muljadi et al., 2004). Spurred largely by improvements in turbine and engine design, DG technologies such as microturbines and reciprocating gas engines have lowered the cost and increased the efficiency of small scale generation technologies. Other advances in net metering, fuel conversion technology, and thermal engineering have followed developments in automation and control, improving the economy of small units and reducing the amount of periodic maintenance and inspection needed. Components of small system technologies can sometimes be mass-produced, translating into more attractive initial capital investment costs (Grubb, 1990; Willis and Scott, 2000; Learner, 2001; Lovins et al., 2002; Capehart et al., 2003; National Commission on Energy Policy, 2004; Brown et al., 2005). The end result of such improvements is enhanced efficiency at modest costs.

Another class of DG technology – combined heat and power (CHP) systems – produces thermal energy and electricity from a single fuel source, thus recycling normally wasted heat through cogeneration (a process in which heat and electricity are both useful end products) and trigeneration (in which electricity, heating, and cooling are produced). As a result, CHP technologies consistently generate electricity with overall fuel efficiencies of 55 to 70% – almost double the efficiency of conventional utility turbine generators, which peaked at about 40 percent in the late 1960s (See Box 7.1) (McCraw, 1984; Hirsh, 1989; U.S. Combined Heat and Power Association, 2006). CHP units also often have lower labor and capital costs (when comparing central power generation costs plus transmission and distribution costs to DG or CHP). And since both renewable energy systems and DG technologies can be used close to the end-user, they minimize efficiency losses through the transmission and distribution network.

In addition, small-scale renewable energy technologies have long been advocated because of their environmental benefits. Consisting of generators that create electricity from sunlight, wind, falling water, sustainable biomass, waste, and geothermal sources, the technologies often are portrayed as serving the needs of society better than technologies that consume coal, natural gas, oil, or nuclear

Box 7.1. Primary Energy's CokeEnergy Facility

Primary Energy Incorporated manages a CHP plant in East Chicago, Indiana, that generates 94 MW of electric power along with 930 thousand pounds per hour (kpph) of steam. By recycling waste heat recovered from coke batteries, the plant supplies one-fourth of Mittal Steel's total electric requirements and 85% of its process steam needs. In addition, Primary Energy claims that the plant displaces an average 13,000 tons of NO_x, 15,500 tons of SO_2, and 5 million tons of CO_2 emissions per year.

fuels, largely because they produce few harmful byproducts. Wind turbines and photovoltaic panels produce electricity without the release of carbon dioxide or other greenhouse gases, and they avoid discharging other pollutants that accompany combustion. The Renewable Energy Policy Project concluded that a single one MW wind turbine running at full capacity for one year displaces more than 1,500 tons of carbon dioxide, 6.5 tons of sulfur dioxide, 3.2 tons of nitrogen oxides, and 60 pounds of mercury (Reeves and Becker, 2003). This attribute would mean that, over the course of its estimated 30 year lifetime, the Tennessee Valley Authority's relatively small 29 MW wind farm located on Buffalo Mountain, Tennessee, would displace more than 390,000 tons of carbon dioxide (operating at 30% capacity).

Meanwhile, most renewable energy systems require no fuel and often need less maintenance than fossil-fueled generators, reducing the risk of interruptions in traditional fuel supplies and minimizing fuel price volatility. Wind turbine technology, for example, has seen many recent advances that have reduced maintenance and lowered overall costs: sophisticated building materials and metal alloys have enhanced the performance of turbine bodies; carbon reinforced fiberglass and epoxy composites have improved turbine blade life expectancy; abrasion resistant tapes have reduced the erosion of blade edges; and insulation and paint improvements have extended the life of electrical generating components by reducing the occurrence of rust. As a result, operation and maintenance over the life of recently built wind turbines amounts to around 1 percent of the total cost of the system, compared to around 4 percent for combined cycle natural gas turbines (Northwest Power Planning Council, 2002; Sagrillo, 2002).

Renewable energy technologies also lessen dependence on fossil fuels, especially those obtained from insecure sources abroad. A greater reliance on renewable resources would hedge against the price volatilities of natural gas – the predominant fuel used in recently built generation capacity – by providing wiggle room in a tight natural gas market. A study undertaken by the Lawrence Berkeley National Laboratory found that increasing the amount of deployed renewable resources between 2 and 20% could depress wellhead natural gas prices between 0.8 and 2.0%. These numbers may not sound like much, but if renewable generation were implemented closer to the 20% range, the net present value of natural gas savings could be as high as $74 billion in the period between 2003 and 2020 (Wiser et al., 2005).

Perhaps most amazingly, renewable energy systems and DG technologies accomplish their social and technical advantages while sometimes producing *cheaper* electricity, especially as fossil fuel prices have escalated since 1999. When levelized costs are taken into consideration, data from the Virginia Center for Coal and Energy Research (Karmis et al., 2005) confirm that wind and landfill-gas generation systems constitute the *cheapest* sources of electricity – cheaper than power derived from advanced coal, natural gas, and nuclear plants (See Table 7.1).[1]

While still comparatively high, the cost of power produced by solar photovoltaic panels, for example, has declined from $13.50 to around $2.00 per watt between 1980 and 2005 (Sheer, 2001; National Renewable Energy Laboratory, 2006). Improvements in wind turbine design have lowered the cost of wind-produced

Table 7.1. Levelized cost of Electricity (LCOE) for Fossil, Nuclear, and Renewable Technologies

Technology	LCOE, in 2005 $/kWh
Wind	.028
MSW-Landfill Gas	.030
Advanced Nuclear	.035
Scrubbed Coal	.044
Integrated Gasification Combined Cycle (IGCC)	.044
Advanced Combined Cycle Gas/Oil	.047
Conventional Combined Cycle (CC) Gas/Oil	.050
Biomass	.050
IGCC with Carbon Sequestration	.059
Advanced Combustion Turbine	.067
Advanced CC with Carbon Sequestration	.069
Conventional Combustion Turbine	.077
Solar, PV (30%)	.235
Solar, PV (10%)	.310

Source: Based on Karmis et al., 2005

electricity to less than 5 cents per kWh in 2002 (down from about 30 cents per kWh in the 1980s) for most areas of the United States (Smith, 2004). This cost compares to around 6 cents per kWh (levelized) for popular gas-turbine plants built from 2000 to 2004.

Besides offering these hard-nosed, quantifiable benefits, the use of DG technologies may offer a more significant promise in the post-September 11, 2001 era – by improving the grid's security. Because of their dispersed nature,

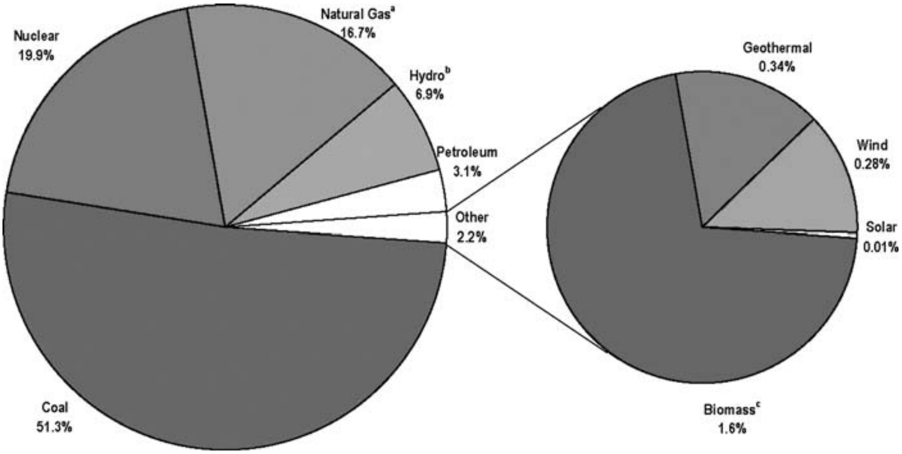

Figure 7.1. U.S. Electricity generation by source, 2003 (Based on Karmis et al., 2005)

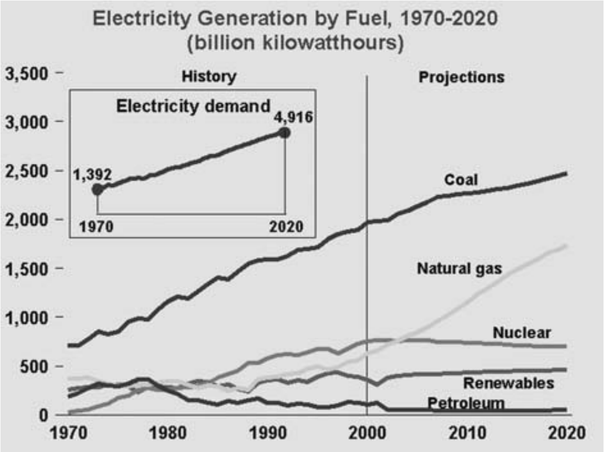

Figure 7.2. U.S. Electricity generation by fuel, 1970–2020 (billion kWh) (Based on dEIA, 2005)

Table 7.2. Existing Capacity by Energy Source, 2005 (MW)

Energy source	Number of generators	Generator nameplate capacity	Net summer capacity	Net winter capacity
Coal[a]	1,526	335,243	313,020	315,364
Petroleum[b]	3,175	37,970	33,702	37,339
Natural Gas	3,048	256,627	224,257	241,391
Dual Fired	3,003	193,115	172,170	184,399
Other Gases[c]	119	2,535	2,296	2,259
Nuclear	104	105,560	99,628	101,377
Hydroelectric Conventional[d]	3,995	77,130	77,641	77,227
Other Renewables[e]	1,608	21,113	18,763	19,000
Pumped Storage	150	19,569	20,764	20,676
Other[f]	42	754	700	716
Total	16,770	1,049,615	962,942	999,749

[a] Anthracite, bituminous coal, subbituminous coal, lignite, waste coal, and synthetic coal.

[b] Distillate fuel oil (all diesel and No. 1, No. 2, and No. 4 fuel oils), residual fuel oil (No. 5 and No. 6 fuel oils and bunker C fuel oil), jet fuel, kerosene, petroleum coke (converted to liquid petroleum, see Technical Notes for conversion methodology), and waste oil.

[c] Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

[d] The net summer capacity and/or the net winter capacity may exceed nameplate capacity due to upgrades and overload capability of hydroelectric generators.

[e] Wood, black liquor, other wood waste, municipal solid waste, landfill gas, sludge waste, tires, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.

[f] Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.

Notes: Where there is more than one energy source associated with a generator, the predominant energy source is reported here. Totals may not equal sum of components because of independent rounding.

Source: Based on dEIA, 2005.

DG technologies may appear less attractive to terrorists than nuclear plants, natural gas refineries, and large transmission facilities, where one well-placed interruption can cause widespread damage to the electrical grid. Employment of decentralized power plants may help insulate parts of the grid from failure if terrorists (or even squirrels, hurricanes, and untrimmed trees) take down a critical component.

Yet despite their immense environmental, technical, and financial promise, DG and renewable-energy technologies still constitute a small percentage of electricity generation capacity in the United States. Excluding large hydroelectric generators, renewable-energy technologies in 2003 comprised about 2% of the U.S. electricity generation mix (Figures 7.1 and 7.2 and Table 7.2). DG/CHP technologies do little better. In 2005, the Energy Information Administration (EIA) characterized only 3.1% of electricity generation capacity as commercial or industrial combined heat and power (33,217 MW out of 1,490,000 MW) (EIA, 2005).

7.3. SIGNIFICANCE OF DISCUSSION ABOUT IMPEDIMENTS TO WIDER USE OF DG TECHNOLOGIES

A discussion of the apparent paradox concerning the underutilization of renewable energy and DG technologies has serious policy implications for at least three reasons. First, understanding the impediments to small and decentralized energy units will become more important as large electricity plants are forced into retirement in urban centers, congested population areas, and pollution non-attainment areas (locations where the government will ban the addition of any pollution-emitting technology). For example, 40% of the U.S. nuclear power plant capacity, which in 2005 contributed about one-fifth of the country's electrical energy, is scheduled to retire by 2020 (See Figure 7.3).

To fill the void left by expiring nuclear, and to meet the growing demand for electricity, business and policymakers need to choose replacement generation technologies. Nuclear power may become more attractive, especially with inducements provided by the 2005 Energy Policy Act. However, if obstacles to nuclear

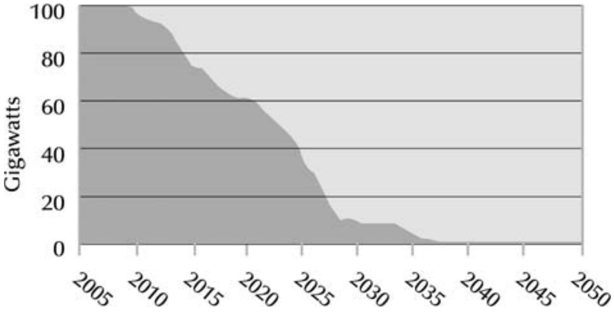

Figure 7.3. Total U.S. nuclear power plant capacity (by License Expiration Date) (U.S. Energy Information Administration, 2005; Figure used with permission from National Commission on Energy Policy)

power remain (such as the inability to find waste repositories, large up-front capital costs, and the difficulty of extracting uranium at competitive prices), and if natural gas and other fossil fuel prices remain high, then renewable energy and decentralized, modular generation technologies may appear more attractive as ways to provide electricity supply. In this case, overcoming the impediments to renewables and DG (along with CHP) becomes essential.

Second, a discussion of the barriers to renewable energy and DG technologies has significance because policy makers are becoming more aware of the external costs (also called "externalities") of electricity generation. Put simply, externalities consist of costs and benefits not borne by the parties of an economic transaction. In most cases, utility managers and regulators tend to undervalue externalities related to power quality, power reliability, and the environment. By omitting discussion of these costs and benefits, policymakers often create an uneven playing field for cost comparisons (Carlin, 1993, p. 3). In fact, some analysts believe the lack of consideration of such costs and benefits may be the greatest impediment to employing renewable energy technologies in the United States, constituting an implicit and significant advantage to fossil and nuclear energy systems.

When dealing with electricity pricing, externalities often include the costs to individuals whose health is impaired by pollution; the value of impaired (or improved) landscapes; and the impact on employment patterns and tax payments. They also subsume the impacts of smog, acid rain, and global climate change, as well as the government's cost to deploy military forces for securing energy resources. Renewable energy technologies, which have been pursued most aggressively since the 1970s, have been largely disadvantaged by the general neglect of consideration of externalities. In one recent study, traditional coal-boiler generation technology appeared to produce relatively cheap power – under 5 cents per kWh over the life of the equipment, which included capital, operating and maintenance, and fuel costs – while wind-turbine generators and biomass plants produced power that cost 7.4 cents per kWh and 8.9 cents per kWh respectively. But when analysts factored in a host of external costs (such as air pollution, land reclamation, and waste disposal), coal-boiler technology costs rose to almost 17 cents per kWh, while wind turbines and biomass plants yielded power costing around 10 cents per kWh (Roth and Ambs, 2004).

Finally, this discussion of impediments is important because it reminds us that large state and federal programs aimed at overcoming the technical difficulties associated with novel energy technologies are often not enough to make them commercially successful. Despite millions of dollars in research and development expenditures, tax breaks, financial assistance, and regulatory incentives in some states, the impediments to DG technologies remain social (i.e., economic, political, and cultural). Until these remaining social barriers are targeted (in the same way that technical impediments were targeted beginning about thirty years ago), the promise of distributed energy systems will remain unfulfilled.

7.4. FEDERAL AND STATE INCENTIVES FOR RENEWABLE ENERGY AND DG TECHNOLOGIES

The potential advantages of renewable energy and distributed generation technologies have attracted policy makers for several decades, especially since the 1970s. At all levels of government, legislators and regulators have occasionally offered inducements for corporations and individuals to employ the technologies, with the hope that a larger market for them would encourage additional research, development, and market acceptance. In this section, we highlight some of the principal federal and state policy incentives.

The major legislative mandate spurring work on renewable energy technologies consisted of the Public Utility Regulatory Policy Act (PURPA) of 1978 (P.L. 95–617). Passed as one of five diluted measures of President Carter's national energy plan, the law primarily encouraged electric utility companies to reform rate structures so customers would reduce wasteful consumption of power. But a single provision of the law also had wide-ranging effects on companies and individuals that sought to use nontraditional sources of energy to produce electricity: it required power companies to purchase electricity produced by nonutilities if generated from efficient cogeneration plants and from renewable energy facilities.[2] Previously, utilities could decline to purchase such power created by these small-scale, decentralized producers, or they could offer low prices to the entrepreneurs who developed them. PURPA, on the other hand, mandated that utilities purchase this power at rates that equaled their own cost of producing electricity.

In some states, regulators set these rates at high levels as a way to encourage production from renewable and cogeneration plants. By doing so, they motivated large research and development efforts, which contributed to declines in the cost of producing power from renewable-energy and cogeneration technologies. Largely because of the stimulation of PURPA, for example, entrepreneurs developed small wind turbines for use in clusters, with the amassed electricity sold to utilities. Costs dropped throughout the 1980s and into the 1990s such that wind turbines now produce larger amounts of power (up to 3 MW per turbine) at costs comparable to fossil fuel (including natural gas) in some parts of the country and cheaper than other non-hydro renewable resource.

The positive effects of PURPA have been limited by subsequent legislation. While the law remains in force (despite efforts to repeal it by those who believe it encourages expensive and unneeded power), the 1992 Energy Policy Act created a new class of independent generators that sell power into an open market (Hirsh, 1999). Moreover, some states have seriously weakened the incentives offered to generating companies that took advantage of PURPA's provisions. While the 2005 Energy Policy Act extended a number of tax credits for novel energy technologies (see Table 7.3), the law further amended PURPA in a way that discourages some nonutility generators to sell power to the grid.[3]

In addition to providing incentives via legislative mandate, the federal government also manages more than 150 energy program activities and offers 11 tax preferences

Table 7.3. Major Production Tax Credit Provisions in the Energy Policy Act of 2005

Resource	Credit size	Special considerations
Wind	Full	None
Biomass		
Closed-loop	Full	Crops grown specifically for energy
Closed-loop co-firing	Full	Only specific coal power plants; based on % of biomass heat input
Open-loop	Half	Does not include co-firing
Livestock waste	Half	> 150 kW; Does not include co-firing
Poultry waste	Full	Incorporated with "livestock waste" with the American Jobs Creation Act of 2004
Geothermal	Full	Can't also take investment tax credit
Solar	Full	Can't also take investment tax credit; eligibility expires 31 December, 2005
Small irrigation hydro	Half	No dams or impoundments; 150 kW–5 MW
Incremental hydro	Half	Increased generation from existing sites
Landfill gas	Half	Can't also take Sec. 29 tax credit
Municipal solid waste	Half	Includes new units added at existing plants

Source: Based on Karmis et al., 2005

for DG and renewable technologies (U.S. Government Accountability Office 2005; DOE, 2006). State governments have also been active in encouraging development of the technologies, by creating at least two major mechanisms: public benefits funds and renewable portfolio standards.

Public benefit funds (PBFs, also called system benefit funds) originated in the 1990s, at a time when state policy makers considered electric utility restructuring legislation. First implemented in Washington State in 1994, public benefit funds were endorsed by the Federal Energy Regulatory Commission (FERC) in 1995 as a way to fund services that had previously been included in the customers' bills from regulated utility companies (Federal Energy Regulatory Commission, 1995). As part of the negotiations for California's restructuring law, environmental advocates won a provision for a public benefit fund that would expend at least $872 million on energy-efficiency work from 1998 to the end of 2001. For renewable energy programs, the fund would allocate $540 million (Wiser et al., 1996; California Energy Commission, 1997). To promote renewable-energy technologies and other programs that would likely wither after deregulation, the California Energy Commission created its Public Interest Energy Research program, which initially drew about $62 million annually from the state's PBF.[4] By mid-2003, twelve states had created PBFs. Seventeen organizations that administer the funds, which are scheduled to total $3.5 billion in a decade, collaborate through a nonprofit organization, the Clean Energy States Alliance. Seeking to expand the use of nonpolluting technologies (with special emphasis on solar, wind, and fuel cells), the organization sponsors original research and collects information and analyses. It seeks to increase the efficiency of the research of state organizations by eliminating duplication of efforts and by providing forums for the states to share knowledge.[5]

Along with public benefit funds in some cases, twenty-two states and the District of Columbia have established "renewable portfolio standards" (RPS, also known as renewable electricity standards) that seek to increase the amount of environmentally benign generation capacity (Petersik, 2004). Simply put, the RPS is a legislative mandate that requires all power producers in a state to employ renewable energy technologies for generation of a certain percentage of energy by a fixed date. Generating companies have the option of building renewable facilities themselves or buying credits from other firms that own them. By giving companies this choice, the RPS creates a market for credits that resembles the federal trading of emissions credits under the 1990 Clean Air Act amendments. It therefore blends the government "command and control" with the free-market approach. Notable states that have created RPS programs include California (which requires 33% renewables by 2030), Hawaii (20% by 2020), New York (25 percent by 2013), Massachusetts (4% by 2009), Minnesota (19 percent by 2015), Nevada (20% by 2015), and Pennsylvania (18% by 2020) (Petersik, 2004; Fialka, 2006).

7.5. IMPEDIMENTS TO RENEWABLE ENERGY AND DG TECHNOLOGIES

The large number of federal and state incentives obviously played an important role in helping increase the market for renewable-energy and DG technologies. As demand for these technologies grew, technical innovation increased, and costs declined. In other words, government support has been successful in helping to advance the technical feasibility of nontraditional technologies and clearing a number of initial economic impediments to renewable energy and DG. Nevertheless, barriers to widespread use of renewable (and other small-scale, distributed) energy technologies remain. In this section, we note the existence of several technical impediments. However, we argue that many of the remaining impediments no longer appear technical, but rather are social. Less easy to isolate and analyze, the social impediments remain the most difficult to overcome.

7.5.1 Difficulty in Setting Universal Standards

As the price of power from renewable-energy and distributed generation technologies has declined in recent years, the major remaining technical impediments appear to deal with difficulties in standardizing the technologies and easily connecting them to the grid. The basic reason for these impediments is easy to understand. Since individual units produce smaller amounts of power than the behemoth power plants traditionally used, DG technologies must be more numerous, requiring more frequent efforts to place them in appropriate locations and to integrate them into the existing power network.

Small scale renewable-energy technologies suffer especially from the difficulty in standardization, as access to renewable "fuels" often dictates site-specific requirements for the units. For example, a wind turbine might work best atop a cloudy mountain, whereas a photovoltaic system might reach optimal performance in a sunny desert. As a result, the costs, capacity, storage needs, and rate of payback will differ for almost every installation of a renewable facility (International Energy Agency, 2002, p. 34; Goett and Farmer, 2003, pp. 20—31; Pepermans et al., 2003, p. 22). The complexity of building a renewable energy plant in the right size and in the proper location makes developing a "standard approach," such as the one in use for constructing large fossil-fueled plants, extremely difficult. Renewable-energy technologies are therefore perceived (perhaps correctly) as more difficult to design and site (Taylor and Van Doren, 2002).

Even after a design has been decided upon, DG technologies face difficulties in the processes of permitting and monitoring. Many authors have warned that the deployment of a large number of small-scale renewable technologies greatly complicates permitting requirements by imposing a huge administrative burden. Likewise, measuring the environmental impacts associated with their construction, generation, maintenance, and decommissioning can overwhelm government regulators (Casazza and Loehr, 2000, p. 301; Zavadil and McGranaghan, 2002). Confirming that view, the Congressional Budget Office noted in 2003 that widespread use of distributed, small-scale renewable energy systems would greatly increase the cost and difficulty of environmental monitoring (Goett and Farmer, 2003, p. 22).

As an example of these problems, consider biomass fuel used for combustion. The variability in the fuel – not just its energy density, but its moisture content, molecular composition, and purity – makes its combustion difficult to regulate. An oak tree burns differently and emits different waste products than do pine trees, tobacco residues, switch-grass, or sweet sorghum.[6] In addition, many biomass fuels – especially municipal waste and construction timber – are contaminated with chemical pollutants, pesticides, and paint. The separation of these non-biodegradable materials from combustible material increases the complexity of bioelectric generation, and it imposes an additional burden for operators to manage and for government agencies to oversee (Masters, 2004, pp. 192–193).

Beyond these problems, DG technologies remain hampered by technical difficulties evidenced when their owners try to connect the generators to the power grid. Naturally, distribution and transmission system operators need to ensure that the hooked-up DG entrepreneurs do nothing that would imperil their ability to maintain voltage control and synchronization. In addition, DG technologies cannot be allowed to endanger the lives of people working on the grid, by adding power to it when utility repairmen think it has been de-energized (Cummings and Marston, 1999, pp. 22–31; Borbely and Kreider, 2001, p. 312; International Energy Agency, 2002, pp. 73–85);. Moreover, most transmission networks have been designed as radial grids, meant only to send power in one direction. DG technologies complicate this design pattern because they enable the distribution of power in the opposite direction. Currently, those using DG technologies often depend on custom-designed electronics packages to solve these problems. The great expense in developing such packages obviously creates a disincentive for new users (Starrs, 2001, pp. 104–109).

7.5.2 Variable and Inconsistent Incentives for Renewable Energy Technologies

As significant as these technical impediments may appear, they pale in light of several obstacles that can be considered social. Having origins in politics, history, and culture, these social “forces” play a huge role in inhibiting the widespread acceptance and use of renewable-energy and DG technologies. The first consists of the variability and inconsistency of government policy. In other words, policies aimed at encouraging DG and renewable-energy technologies have changed frequently, discouraging their widespread adoption.

Because of his beliefs that esteemed personal sacrifice and changes in fundamental values concerning consumption, for example, President Jimmy Carter advocated legislation, regulations, and tax credits to spur energy-efficiency and renewable-energy technologies. In contrast, Ronald Reagan symbolically removed the solar collectors from the roof of the White House and took more substantive measures to end federal programs and tax credits that encouraged efficiency and alternative energy technologies (Behr, 1981; Greene, 1986). As a result, federal renewable energy R&D budgets (in 2000 dollars) fell precipitously from $4.7 billion in 1978 to $1.8 billion in 1988 (National Commission on Energy Policy, 2004) (See Figure 7.4).

Reversing this trend somewhat, the 1992 Energy Policy Act, signed by Reagan’s successor, George H.W. Bush, provided a production tax credit for certain renewable-energy technologies. But those credits expired in 1999, and environmental advocates worked diligently to win Congressional approval for their restoration, often on an annual basis (Giovando, 1999, p. 47). When Congress failed to renew the credits before the end of 2001, investment in wind turbine projects declined precipitously. Developers installed only 410 MW of new wind turbines in 2002, down from about 1,600 MW in 2001 and 2003 (American Wind

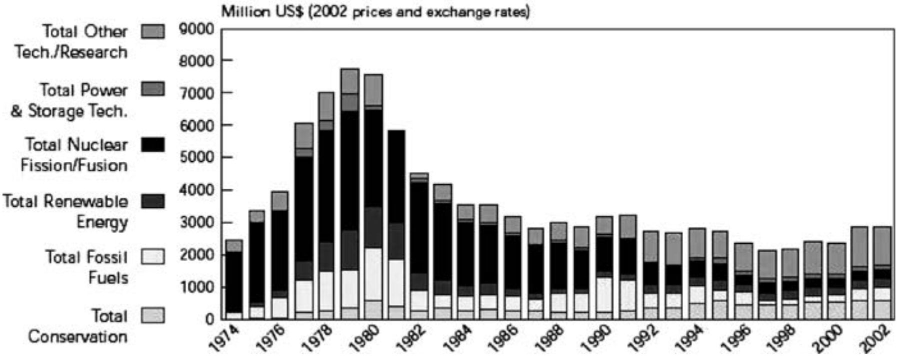

Figure 7.4. U.S. DOE Energy Research and Development 1974–2002 (modified from International Environmental Agency 2004)

Energy Association, 2004a). Congress reinstated the credits in March 2002 for the remaining nine months of the year and for all of 2003. But the failure to extend the credit before the end of 2003 meant another bust cycle for the wind turbine industry (American Wind Energy Association, 2004b). Analysts expected another boom cycle with passage of the 2005 Energy Policy Act, but even that law extends the credits only for construction of projects completed before the end of 2007.[7]

The variability of policy relating to renewable-energy technologies serves as a serious social impediment. Entrepreneurs appreciate consistent conditions upon which to make financial and managerial decisions. Forecasts of profitability usually require data concerning tax credits, depreciation schedules, cash flows, and the like. When policymakers frequently change the factors that go into these financial calculations, they insert an extra level of uncertainty into the decision-making process. Consequently, policy variability undermines the value of some of the incentives.

7.5.3 Lingering Utility Monopoly Rules and a History of Control

Policy variability does not totally explain the difficulty entrepreneurs experience when employing DG technologies that have already become relatively mature, such as cogeneration plants and wind turbines. More significantly, perhaps, these projects face hurdles when dealing with the administrators of the existing transmission and distribution systems, who seek to retain a number of traditional, "time-tested" regulatory and utility practices. Also seeking to maintain control over a system they (and their predecessors) created, they have made it difficult for new players to play on their turf.

These practices begin with the imposition of fees to connect to the grid. In many states that have begun restructuring their utility systems, formerly regulated natural monopoly power companies have been permitted to charge customers "stranded costs." These costs are intended to cover a fair return on generation and transmission investments made by utilities during the era of regulation, when the investments were viewed as serving all users. Put simply, when a customer decides to install an electric generator independent of the utility, he or she arguably removes part of the grid's existing load requirement and "strands" part of the investment made earlier by the power company. But such fees greatly increase the cost of renewable energy systems because customers must pay them in addition to the cost of buying the new technology (Maloney and Brough, 1999; Allen, 2002).

Utilities also require payment of a host of charges on those who use certain renewable energy systems. For example, companies may demand high rates for providing backup power for when the intermittent renewable-energy technologies do not produce power. They may also charge a demand fee, a charge that penalizes customers for displacing demand from utilities. A recent study undertaken by the National Renewable Energy Laboratory found more than seventeen different "extraneous" charges associated with the use of dispersed renewable technologies (Alderfer and Starrs, 2000). These types of charges, the senior editor of *Public*

Utilities Fortnightly exclaimed, constitute "a major obstacle to the development of a competitive electricity market" (Stavros, 1999, p. 34).

A more significant impediment may occur when nonutility companies or individuals attempt to connect DG technologies to the grid, usually to sell power to the utility or other customers. Interconnection procedures that have been implemented – when they exist at all – vary greatly between utilities, municipalities, cities, and states (Kolanowski, 2000, pp. 42–43; Allen, 2002, pp. 507). For example, the PJM Interconnection – the independent service operator responsible for a large power grid in the Northeast – mandates that customers wishing to interconnect distributed generators to the utility's transmission network conduct an extensive feasibility study that requires a $10,000 deposit (PJM Interconnection, 2005). This fee can serve as a significant disincentive to some people seeking to employ small-scale power generators. Overall, interconnection problems prevent DG technologies from being fully preassembled for "plug and play" style installation, and they make it difficult for industries or corporations to install DG systems in more than one region (since they then must accommodate competing standards and rules) (Nadel, 2001, pp. 53–54). Various organizations, such as the National Association of Regulatory Utility Commissioners, the Federal Energy Regulatory Commission, and the Institute of Electrical and Electronics Engineers (IEEE) have recognized the interconnection impediment and have encouraged establishment of standardized requirements as a way to overcome it.

To be sure, some of these utility practices (especially the imposition of fees) make sense from the perspective of incumbent power companies that appear to be losing business to DG operators. And given the history of regulation, in which utilities were required to make investments to meet the needs of all customers, the former monopolies seem justified in seeking repayment of past expenses. Nevertheless, the fees and other efforts to thwart the goals of DG entrepreneurs also appear based on the desire by utility managers to achieve other goals, such as the desire to remain in control of "their" system. Often viewing themselves as the heirs to stewards of technological and social progress, they look fondly to the relatively successful role played by utility companies for decades in providing abundant and cheap supplies of electricity to grateful users. Widespread electrification and inexpensive power promulgated the highest material standard of living in the world, as Americans enjoyed electrical appliances that enhanced their productivity, comfort, and entertainment. Despite the industry's inability to continue its trend toward more efficient large-scale power plants since the 1970s (Hirsh, 1989, 1999), many of the traditionally trained managers of utilities still take pride in thinking that they (and their ancestors) had done an exemplary job in keeping the lights on. That attitude may have been reinforced as restructuring efforts of the utility system in the 1990s contributed (at least in their minds) to the California electricity crisis of 2000 to 2001 and to the Northeast blackout of 2003. It is an attitude that resists, often quite aggressively, the idea that "outsiders" should be permitted to attach nonutility equipment to the grid that they had so carefully built and managed.

One might imagine that after two decades of experience with nonutility generators (i.e., after implementation of PURPA rules starting in the 1980s), traditional utility managers would have given up such resistance. But that is not always the case, as a recent experience demonstrated. Starting in 1998, managers of a rural coop spent seven years trying to stop a family farmer in Iowa from connecting a wind turbine to the power company's distribution lines. The farmer sought to obtain net metering rates from the coop under the provisions of PURPA, appealing to Iowa's court system and FERC. Ultimately, FERC ruled in favor of the farmer, and it scolded the coop's managers for deliberately disconnecting the family, for using delaying tactics, and for arguing disingenuously to the courts and to FERC.[8]

7.5.4 Resistance to Change and Public Misunderstanding

Reinforcing the desire to maintain control over as much of the utility system as possible, conventional utility mangers often resist the notion of change. History plays a big role in this resistance. From the beginning of the twentieth century until the 1970s, the industry took advantage of incrementally improving, large-scale technology and managerial innovations to produce huge amounts of power at declining costs (Hirsh, 1989). In addition, utility managers situated most large plants built after the 1950s outside cities. Urban expansion depleted the amount of property available for land-intensive electricity generators, and residents living in American cities became more aware of air pollution and environmental problems with energy production. Planners located nuclear plants outside cities as a safety measure as well. The advantages of this classical system – cheaper electricity prices and steady profits in the industry – appeared self-evident despite some efficiency losses (largely from transmission and distribution of power) and the cost of meeting regulatory obligations. Consequently, utility managers developed a deeply engrained way of thinking. Adopting a similar mindset, politicians often consider large, centralized, and distantly located plants as the best way to provide power. This tacit and widespread belief among business and policy leaders discourages consideration of novel options for power generation, such as renewable-energy and DG technologies.

Likewise, the public's lack of knowledge about the utility system serves as an impediment to the adoption of DG technologies. As historian James C. Williams explains, people realize that technological systems are tools with which they interact. But once technological landscapes are in place, people fold them so completely into their psyches that those very landscapes become almost invisible (Williams, 2001). In other words, once electric power became part of people's lives, they rarely thought about how it was produced and how it got to them. In a 1978 study conducted by Southern California Edison, the most common answer to the question "where does electricity come from" was "from the socket in the wall" (Sovacool, 2006, p. 254). Consequently, consumers often oppose renewable-energy technology not because they believe it is a poor alternative to fossil fuels, but because they do not realize that new plants of any type appear necessary to provide additional electricity. They would object as strongly to plans to build traditional power plants as well, simply because (unless they already live near a power plant) they generally do not think about where power originates and how it travels to their premises.

Furthermore, most people do not want to think about generating power at their workplace or home. Managers of businesses always remain constrained by limited resources and time, and they believe that they can maximize their profits by focusing on core, nonenergy related issues. Rodney Sobin, formerly a technology manager at the Virginia Department of Environmental Quality, observed that:

> The potential users of DG tend to be unfamiliar with the benefits such systems offer. The cookie baker is concerned with making a better chocolate chip cookie. The Chicken McNugget manufacturer is concerned with perfecting a better Chicken McNugget. The shopping mall managers are interested in providing retail services. None of them are interested in generating power and becoming a micro- or quasi-utility.
>
> (Sovacool, 2006, p. 89)

Ironically, perhaps, people have become accustomed to low-priced electricity, and they often consume it indiscriminately, creating demand for construction of new power plants. Consequently, Americans' preferences for sprawling growth, automobiles, individual comfort, and huge electricity consumption impose conditions on their future energy choices. Historian David Nye notes that, "Americans have built energy dependence into their zoning and their architecture…they think it natural to demand the largest per capita share of the world's energy supply" (Nye, 1999, pp. 257–258). Moreover, patterns of over-consumption have largely become engrained and invisible to most people. In other words, Americans simultaneously create a demand for more electricity, but they frequently oppose construction of new generation facilities (including renewable-energy and DG technologies). They simply do not realize that they contribute to the necessity of new plants.

The preference for centralized power plants and the public's uninformed contribution to the growing demand for them resulted from decades of historical experiences that have become part of the American energy culture. More than just an interesting sociological insight, the culture has at least two significant implications for the future deployment of renewable-energy and DG technologies. First, because such thinking has become institutionalized and self-sustaining within the electric utility and government communities, policy makers will continue to seek construction of massive electrical generators as the "technology of choice." After all, the selection of familiar, large-scale, centralized technologies has generally led to creation of the biggest and most reliable utility system in the world (some say). In the risk-averse world of utility managers and legislators, policymakers naturally resist adopting novel and less-experienced renewable energy technologies, even if they realize that anomalies exist with the existing paradigm.

Second, the general public's ignorance of the sources of electric power translates into opposition to almost any additional component of the power system, whether it be a transmission line, a nuclear power plant, or a wind turbine. While people acknowledge the need for electricity, they do not want to see elements of the power infrastructure near their homes. A small number of people would therefore oppose construction of a big, centralized power plant – especially one built outside of population centers. However, more people would object to the greater number of installations of DG facilities needed to create the same amount of power. Put differently, the decentralized nature and small scale of DG technologies makes them especially visible and objectionable to a larger number of people, despite inherent benefits to the utility system. And as Americans (and others around the globe) become increasingly aware that all energy technologies – including renewable-energy technologies – contain environmental downsides, the new distributed systems painfully bring what previously seemed "invisible" to the foreground.[9] It appears that the technical or economic benefits cannot totally trump the public's disapproval of the highly evident and intrusive DG technologies.

7.6. CONCLUSION

Distributed generation and renewable-energy technologies present a host of potential advantages: in some cases, they produce power more cheaply than traditional fossil-fuel burning generators; they can provide a secure, efficient, and reliable source of power; they offer electricity with reduced environmental harm; and they can meet increased demand for power without exacerbating problems on the strained distribution and transmission grid. Despite offering these benefits, DG and renewable-energy technologies face certain technical hurdles, in the form of connecting safely with the existing electric power network, for example. Moreover, these technologies often prove difficult to standardize, being susceptible to location-specific sources of natural "fuel" and other resources.

Nevertheless, the novel technologies appear more hampered by a host of impediments that can be classified as social. Government policy for DG and renewable-energy technologies have helped advance their technical and economic feasibility, but legislative action occurs inconsistently, affected by a host of political and ideological factors. As important, business managers and political leaders who still retain control in the electric utility system have erected barriers that discourage nontraditional participants to enter the power generation business. Finally, the public's lack of knowledge about electricity production and its use often leads to greater opposition to a large number of small, distributed power units (even those that create less environmental harm) than to a smaller number of traditional fossil-fuel burning plants located far from load centers.

Ironically, a move toward more distributed energy systems would represent a conservative – not a radical – move in at least one sense, if only people recalled the industry's history. When Thomas Edison inaugurated the electric utility industry in 1882, he supplied direct-current (DC) power to a host of nearby businesses in the financial district of New York. Because DC power could not be transmitted over long distances, Edison sold small-scale generation equipment to commercial customers (such as hotels and industrial firms) that had large demands for electricity. Individual homeowners would be served by small power stations such as Edison's original plant, which would be dotted throughout cities at regular intervals. This model, of course, became displaced by one that employed large centralized power stations to create huge amounts of power sent over alternating-current (AC) transmission networks. Surmounting the distribution problem posed by Edison's DC arrangement, the AC approach lent itself better to the economies of scale that became apparent in generating equipment over the next eight decades. The use of smaller, modular, and decentralized energy systems in the first part of the twenty-first century could be viewed as a long and tedious journey that leads to where we started more than 120 years ago.

But a return to the utility system's historical roots today would require a significant transfer of power (pun intended). Even though the technological basis for the utility system today appears shaky – with large scale generation and transmission technologies offering fewer economic benefits along with increased security and reliability threats – traditional utility and political leaders still appear to retain a large amount of control over the makeup of the power system. To be sure, they may be fighting a losing battle, as did managers of other industries that once valued large scale. In the steel, biotechnology, agriculture, microelectronics, pharmaceutical and mining industries, companies have begun employing small-scale technologies to gain increased flexibility, security, and lower costs (D'Costa, 1999; Cortada, 2003; Friedman, 2006). Still, utility executives retain power now, and many of them use it to impede widespread use of DG and renewable energy technologies.

This analysis of the impediments of DG and renewable energy technologies should remind policymakers that the biggest obstacles for meeting rising demand for electricity (and energy overall) may be social rather than technical. The difficulty in standardizing, permitting, interconnecting, and monitoring great numbers of decentralized generators – along with the inconsistency of policy incentives sponsored by state and federal governments – remain significant obstacles. Lingering utility rules place new technologies at a financial disadvantage by helping incumbent power companies retain control of their network. And resistance to change and public misunderstanding about the origins of electricity will continue to complicate any supply-side solution to the country's energy problems. These impediments – not poor technical design – prevent a broader transition to more environmentally friendly and cost-effective DG technologies. And here lies the most serious paradox: for the moment, those electricity generators that offer hugely attractive benefits in terms of efficiency, cost, emissions, and security are those that provide only a tiny percentage of electricity in the United States. For these technologies to gain greater acceptance, they need not be redesigned technically, but reconceptualized socially.

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NOTES

[1] Many energy experts contend that the most appropriate measure of the cost to produce electricity is the levelized cost of electricity (LCOE). The capital cost of a technology only tells part of the story. Traditional technologies may have lower up-front capital costs, but over time, the savings are eaten away by the cost of the fuel they consume. Renewable technologies, in contrast, do not consume expensive fuels, but cost more up-front to install. In addition, not all traditional plants have low capital costs. The costs of some nuclear plants completed in the 1980s cost up to $5,000 per kW due to poor construction, high interest rates, and licensing and permitting obstacles. The LCOE is a lifecycle estimate of the cost to generate power with a particular generation source, and it considers capital and operations costs, fuel costs, financing expenses, taxes, and incentives. To quote from a recent Congressional Budget Office report (Goett and Farmer, 2003) on distributed generation,

"[a]lthough consideration of a technology's capital costs can be important when choosing to invest in distributed generation, estimates of what economists refer to as long-run average costs—costs per unit of output that reflect capital and operating expenses—are generally the more important for investment decisions."

The report continues to state that

"perhaps more relevant for comparing distributed generation technologies with one another and with utility costs and residential prices is a commonly used index of long-run costs known as the levelized cost. Levelized cost is. . .defined as the net present value of all direct costs (for capital, fuel, and O&M) over the expected lifetime of the system, divided by the system's total lifetime output of electricity."

[2] The term "cogeneration" is now commonly referred to as combined heat and power (CHP) and refers to any electrical generator that also generates useable heat (or chilling) in addition to electricity.

[3] P.L. 109–304, signed 8 August 2005, Section 1253 of the Energy Policy Act of 2005, "Cogeneration and Small Power Production Purchase and Sale Requirements."

[4] An overview of the PIER program can be found by visiting http://www.energy.ca.gov/pier/(accessed July, 2006).

[5] For more information, visit the website of the Clean Energy States Alliance, accessed May 2005 at http://www.cleanenergystates.org/index.html.

[6] Most biomass fuels also possess high water content and are often wet when burned. Consequently, large amounts of wasted energy go up the stack as water vapor, leading to relatively low thermal efficiencies for converting fuel to electricity – usually less than 20%. On one hand, this statistic reveals two important advantages of biomass combustion, namely the ability to combust a variety of fuels, making the likelihood of fuel shortage unlikely, and that the steam produced by bioelectricity would be ideal for CHP applications. On the other hand, it also means more fuel must be burned to produce electricity. The result tends to be slightly more expensive electricity, often around 9 cents per kWh, using conventional means of analysis (in which externalities are not included, for example).

[7] Interestingly, the act offers a production tax credit for new nuclear plants until the end of 2020. The disparity between the credits for wind and nuclear energy technologies may result from the fact that commercial wind turbines exist today, while new versions of nuclear plants do not.

[8] For more details of this case, see "Order Initiating Enforcement Proceeding and Requiring Midland Power Cooperative to Implement PURPA," FERC docket No. EL05-92-000, issued 6 June 2005, accessed July 2006 at http://www.ferc.gov/EventCalendar/Files/20050606170606-EL05-92-000.pdf. FERC commissioners noted "we cannot help but note that Midland [the coop] has used the legal process to thwart efforts to compel it to comply with PURPA for seven years, with a long history of using every means at its disposal to avoid its obligation to purchase from [the farmer's] small wind powered QF." For a summary of this and other cases, "Connecting to the Grid: FERC Rules PURPA Supports Net Metering," Interstate Renewable Energy Council, accessed July, 2006 at http://www.irecusa.org/articles/static/1/1114631056_1051597266.html.

[9] People have become rightly aware that even renewable-energy technologies, which use no fossil fuels at all, still retain a host of environmental downsides. Opponents to wind turbines, for example, note their aesthetic drawbacks, their noise levels, their use of land that could be put to other use, and their contribution to the deaths of birds and flying mammals. This last claim has become hotly contested, however. A 1992 California Energy Commission study estimated than more than 1,766 and 4,721 wild birds die each year at the Altamount Pass Wind Resource Area, where more than 5,400 wind turbines operated. Several studies conducted in the Appalachian Mountains (focused on the region from Tennessee to Vermont) have found that large numbers of nocturnal migrants (including bats) are uniquely at risk of colliding with wind turbines. To be fair, however, these mortality rates pale in comparison to death resulting from other man-made objects. Tall, stationary communications towers, for instance, have been estimated to kill more than 4 million birds each year. Moreover, death-rates of all flying animals have decreased in recent years as wind-power entrepreneurs have installed larger turbine blades that turn more slowly and as they used advanced thermal monitoring and radar tracking to install turbines more carefully. For more information, see Karmis et al., 2005.

REFERENCES

Alderfer, R. Brent and Starrs, Thomas J.: 2000, "Making Connections: Case Studies of Interconnection Barriers and Their Impact on Distributed Power Projects," National Renewable Energy Laboratory Report NREL/SR-200-28053, NREL, Golden, CO, USA.

Allen, Anthony: 2002, "The Legal Impediments to Distributed Generation," *Energy Law Journal* 23, pp. 505–523.

American Wind Energy Association: 2004a, "Wind Group Says Loss of Tax Credits Stalls 1,000 MW," *Megawatt Daily* 9 (6 January 2004), p. 8.

American Wind Energy Association: 2004b, "Tax Credit Expiration Hurting Wind Industry: AWEA," *Megawatt Daily* 9 (13 May 2004), p. 9.

Behr, Peter: 1981, "Solar Electric Industry Worried Reagan Might Pull the Plug," *Washington Post*, 29 September, p. D7.

Borbely, Ann-Marie and Kreider, Jan F.: 2001, *Distributed Generation: The Power Paradigm for the New Millennium*, CRC Press, New York, USA.

Brown, Marilyn A., Southworth, Frank, and Stovall, Theresa K.: 2005, "Towards a Climate-Friendly Built Environment," Pew Center on Global Climate Change, [online] http://www.pewclimate.org/global-warming-in-depth/all_reports/buildings/index.cfm, accessed June 2006.

California Energy Commission: 1997, Renewables Program Committee, "Policy Report on AB 1890, Renewables Funding," no date, but an accompanying letter was dated 7 March 1997.

Capehart, Barney L., Mehta, Paul, and Turner, Wayne: 2003, "Distributed Generation and Your Energy Future." *Cogeneration and Distributed Generation Journal* 18(4), pp. 17–33.

Carlin, John: 1993, "Environmental Externalities in Electric Power Markets: Acid Rain, Urban Ozone, and Climate Change," U.S. Energy Information Administration, http://www.eia.doe.gov/cneaf/pubs_html/rea/feature1.html, accessed June 2006.

Casazza, John A. and Loehr, George C.: 2000, *The Evolution of Electric Power Transmission Under Deregulation: Selected Readings*, IEEE, New York, NY, USA.

Chambers, Ann, Schnoor, Barry, and Hamilton, Stephanie: 2001, *Distributed Generation: A Nontechnical Guide*, PenWell Publishers, London, UK.

Chaurey, Akanksha, Ranganathan, Malini, and Mohanty, Parimita: 2004, "Electricity Access for Geographically Disadvantaged Rural Communities – Technology and Policy Insights," *Energy Policy* 32, pp. 1693–1705.

Collins, Harry and Pinch, Trevor: 1998, "The Naked Launch: Assigning Blame for the *Challenger* Explosion," in Harry Collins and Trevor Pinch (eds) *The Golem at Large: What You Should Know About Technology*, Cambridge University Press, Cambridge, MA, USA, pp. 30–56.

Cortada, James W.: 2003, *The Digital Hand: How Computers Changed the Work of American Manufacturing, Transportation, and Retail Industries*, Oxford University Press, Oxford, UK.

Cummings, Francis H. and Marston, Philip M.: 1999, "Paradigm Buster: Why Distributed Power will Rewrite the Open-Access Rules," *Public Utilities Fortnightly* 137 (October 15), pp. 22–31.

D'Costa, A.: 1999, *The Global Restructuring of the Steel Industry: Innovations, Institutions, and Industrial Change*, Routledge, New York, NY, USA.

[EPRI] Electric Power Research Institute: 2003, *Electricity Technology Roadmap: Meeting the Critical Challenges of the 21st Century*, EPRI, New York, NY, USA.

[FERC] Federal Energy Regulatory Commission: 1995, "Promoting Wholesale Competition Through Open Access Non-Discriminatory Transmission Services by Public Utilities and Recovery of Stranded Costs by Public Utilities and Transmitting Utilities, Notice of Proposed Rulemaking and Supplemental Notice of Proposed Rulemaking, Docket Nos. RM95-8-000 and RM94-7-001, Washington, DC, USA.

Fialka, John J.: 2006, "States Power Renewable-Energy Push," *Wall Street Journal*, June 14, 20, p. B2.

Flink, James M.: 1970, *America Adopts the Automobile, 1895–1910*, MIT Press, Cambridge, MA, USA.

Flink, James M.: 1990, *The Automobile Age*, MIT Press, Cambridge, MA, USA.

Friedman, Yal: 2006, *Building Biotechnology: Starting, Managing, and Understanding Biotechnology*, Thinkbiotech, New York, USA.

Giovando, Carol Ann: 1999, "Despite Banner Year, Wind Energy Faces Major Challenges," *Power* 143 (November/December).

Goett, Andrew and Farmer, Richard: 2003, "Prospects for Distributed Electricity Generation: A CBO Paper", Congressional Budget Office, Washington, DC, USA.

Graves, R.L., West, C.D, and Fox, E.C.: 1981, *The Electric Car – Is It Still the Vehicle of the Future?* Oak Ridge National Laboratory, Oak Ridge, TN, USA.

Greene, Stephen: 1986, "Solar Energy Industry Slips Into the Shadows; Fall in Oil Prices, Changes in Tax Rules Hurt Sales," *Washington Post* (9 November), p. B1.

Grubb, M.J.: 1990, "The Cinderella Options: A Study of Modernized Renewable Energy Options." *Energy Policy* (July/August), pp. 525–542.

Hirsh, Richard F.: 1989, *Technology and Transformation in the American Electric Utility Industry*, Cambridge University Press, New York, USA.

Hirsh, Richard F.: 1999, *Power Loss: The Origins of Deregulation and Restructuring in the American Electric Utility System*, MIT Press, Cambridge, MA, USA.

[IEA] International Energy Agency: 2002, *Distributed Generation in Liberalized Electricity Markets*, International Energy Agency, Paris, France.

International Energy Agency: 2004, *Renewable Energy: Market and Policy Trends in IEA Countries*, IEA Publishing, Paris, France.

Karmis, Michael, Abiecunas, Jason, Alwang, Jeffrey, Aultman, Stephen, Bird, Lori, Denholm, Paul, Heimiller, Donna, Hirsh, Richard F., Milbrandt, Anelia, Pletka, Ryan, Porro, Gian, and Sovacool, Benjamin K.: 2005, *A Study of Increased Use of Renewable Energy Resources in Virginia*, Virginia Center for Coal and Energy Research, Blacksburg, VA, [online] http://www.energy.vt.edu/Publications/Incr_Use_Renew_Energy_VA_rev1.pdf, accessed July 2006.

Kirsch, David A.: 2000, *The Electric Vehicle and the Burden of History*, Rutgers University Press, New Brunswick, NJ, USA.

Kolanowski, Bernard F.: 2000, *Small-Scale Cogeneration Handbook*, The Fairmont Press, Liburn, GA.

Kurtz, Sarah and Lewandowski, Allan: 2004, "Recent Progress and Future Potential for Concentrating Photovoltaic Power Systems." Report to the National Renewable Energy Laboratory, [online] http://www.nrel.gov/docs/fy04osti/36330.pdf, accessed July 2006.

Learner, Howard A.: 2001, "Cleaning, Greening, and Modernizing the Electric Power Sector in the Twenty-First Century," *Tulane Environmental Law Journal* 14, pp. 277–314.

Liss, William E.: 1999, *GRI Technical Paper: Natural Gas Power Systems for the Distributed Generation Market*, Power-Gen International, New Orleans, LA, USA.

Lovins, Amory, Datta, E. Kyle, Feiler, Thomas, Lehmann, Andre, Rabago, Karl, Swisher, Joel, and Wicker, Ken: 2002, *Small is Profitable: The Hidden Benefits of Making Electrical Resources the Right Size*, Rocky Mountain Institute, Snowmass, CO, USA.

Maloney, Michael T. and Brough, Wayne: 1999, *Promise for the Future, Penalties From the Past: The Nature and Causes of Stranded Costs in the Electric Industry*, Citizens for a Sound Energy Foundation, Washington, DC, USA.

Masters, Gilbert M.: 2004, *Renewable and Efficient Electric Power Systems*, Wiley and Sons, London, UK, p. 192.

McCraw, Thomas K.: 1984, *Prophets of Regulation: Charles Francis Adams, Louis D. Brandeis, James M. Landis, Alfred E. Kahn*, Belknap Press, New York, NY, USA.

McVeigh, James, Burtraw, Dallas, Darmstadter, Joel, and Palmer, Karen: 1999, "Winner, Loser, or Innocent Victim? Has Renewable Energy Performed as Expected?" *Resources for the Future Discussion Paper 99–28* (June), Resources for the Future, Washington, DC, USA.

Moms, Gijs P.A. and Kirsch, David A.: 2001, "Technologies in Tension Horses: Electric Trucks and the Motorization of American Cities, 1900–1925," *Technology & Culture* 42, pp. 489–518.

Muljadi, E., Wang, C., and Nehrir, M.H.: 2004, "Parallel Operation of Wind Turbine, Fuel Cell, and Diesel Generation Sources." *Presentation at the IEEE-Power Engineering Society General Meeting, Denver, Colorado, June 6–10, 2004*, [online] http://www.nrel.gov/docs/fy04osti/35353.pdf, accessed July 2006.

Nadel, Steven: 2001, "National Energy Policy: Conservation and Energy Efficiency," *Hearing Before the Subcommittee on Energy and Air Quality of the House Committee on Energy and Commerce* (June 22), pp. 53–54, [online] http://energycommerce.house.gov/107/hearings/06222001Hearing265/hearing.htm, accessed July 2001.

National Commission on Energy Policy: 2004, "Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges," [online] http://www.rff.org/rff/Events/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=18167, accessed on June 21, 2006.

National Renewable Energy Laboratory: 2006, "PV Manufacturing R&D," [online] http://www.nrel.gov/ncpv/pv_manufacturing/cost_capacity.html, accessed July 2006.

Northwest Power Planning Council: 2002, "Natural Gas Combined Cycle Power Plants." *New Resource Characterization for the Fifth Power Plan*, [online] http://www.westgov.org/wieb/electric/Transmission%20Protocol/SSG-WI/pnw_5pp_02.pdf, accessed July 2006.

Nye, David E.: 1999, *Consuming Power: A Social History of American Energies*, MIT Press, London, UK.

O'Shaughnessy, Brian: 2005, "Power Generation Resource Incentives and Diversity" *Hearing Before the Committee on Energy and Natural Resources of the U.S. Senate* (May 8), Government Printing Office, Washington, DC, National Energy Policy Development Group.

Pepermans, Guido, Driesen, Johan, and Haelseldonckx, Dries: 2003, "Distributed Generation: Definition, Benefits, and Issues." *Energy Policy* (August), pp. 21–29.

Petersik, Thomas: 2004, *State Renewable Energy Requirements and Goals: Status Through 2003*, Energy Information Administration, Washington, DC, USA.

PJM Interconnection LLC: 2005, "OATT Attachment Feasibility Study Agreement Form," 2005, [online] http://www.pjm.com/planning/expansion-planning/form-oatt-feas-study.html, accessed July 2005.

Rae, John B.: 1955, "The Electric Vehicle Company: A Monopoly That Missed," *Business History Review* 29(4), pp. 298–311.

Reeves, Ari and Becker, Fredric: 2003, *Wind Energy for Electric Power: A REEP Issue Brief.* Renewable Energy Policy Project, Washington, DC, USA.

Roth, Ian F. and Ambs, Lawrence L.: 2004, "Incorporating Externalities into a Full Cost Approach to Electric Power Generation Life-cycle Costing," *Energy* 29, pp. 2125–2144.

Sagrillo, Mick. "Wind System Operations and Maintenance Costs." *American Wind Energy Association Technical Information Brief*, February, 2002, [online] http://www.awea.org/faq/sagrillo/ms_OandM_0212.html, accessed July 2006.

Sheer, Hermann: 2001, *A Solar Manifesto: The Need for a Total Energy Supply and How to Achieve It*, Earthscan Publications, New York, USA.

Smith, Rebecca: 2004, "Not Just Tilting Anymore," *Wall Street Journal* (October 14), C1.

Sovacool, Benjamin K.: 2006, "The Power Production Paradox: Revealing the Socio-technical Impediments to Distributed Generation Technologies," *Ph.D. Thesis*, Science and Technology Studies Department, Virginian Tech, Doctoral Dissertation, Blacksburg, VA, [online] http://scholar.lib.vt.edu/theses/available/etd-04202006-172936/, accessed July 2006.

Starrs, Thomas J.: 2001, "National Electricity Policy: Barriers to Competitive Generation," *Hearing Before the Subcommittee on Energy and Air Quality House Committee on Energy and Commerce*, July 27, Government Printing Office, Washington, DC, USA, pp. 104–109

Stavros, Richard: 1999, "Distributed Generation: Last Big Battle for State Regulators?" *Public Utilities Fortnightly* 137 (October 15), pp. 34–43.

Taylor, Jerry and Van Doren, Peter: 2002, "Evaluating the Case for Renewable Energy: Is Government Support Warranted?" *Cato Institute Policy Analysis*, No. 422. January 10, pp. 1–15.

U.S. Combined Heat and Power Association: 2006, "CHP Technology and Applications," [online] http://uschpa.admgt.com/techapps.htm, accessed July 2006.

[DOE] U.S. Department of Energy: 2006, "Department of Energy Requests $23.6 Billion for FY 2007" [online] http://www.energy.gov/news/3150.htm, accessed February 2006.

[EIA] U.S. Energy Information Administration: 2005, "Existing Capacity by Producer Type," [online] http://www.eia.doe.gov/cneaf/electricity/epa/epat2p3.html, accessed July 2005.

U.S. Government Accountability Office: 2005, "National Energy Policy: Inventory of Major Federal Energy Programs and Status of Policy Recommendations," *United States GAO Report to Congress*, (GAO-05-379) GAO, Washington, DC, USA.

Williams, James C.: 2001, "Strictly Business: Notes on Deregulating Electricity," *Technology & Culture* 42, pp. 626–630.

Willis, H. Lee and Scott, Walter G.: 2000, *Distributed Power Generation: Planning and Evaluation*, Marcel Dekker, New York, NY, USA.

Wiser, R., Pickle, S., and Goldman, C.: 1996, "California Renewable Energy Policy and Implementation Issues – An Overview of Recent Regulatory and Legislative Action," Report LBNL-39247, UC-1321, [online] http://eetd.lbl.gov/ea/emp/reports/39247.pdf, accessed July 14, 2006.

Wiser, Ryan, Bolinger, Mark, and St. Clair, Matt: 2005, *Easing the Natural Gas Crisis: Reducing Natural Gas Prices Through Increased Deployment of Renewable Energy and Energy Efficiency*, LBNL-56756, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Zavadil, Robert and McGranaghan, Mark: 2002, "Working Group Struggles with DG Interconnection Standard." EC&M, [online] http://www.powerquality.com/mag/power_working_group_strugges/, accessed March 2005.

CHAPTER 8

ENERGY MYTH SEVEN – RENEWABLE ENERGY SYSTEMS COULD NEVER MEET GROWING ELECTRICITY DEMAND IN AMERICA

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This chapter refutes the myth that renewable energy resources are insufficient or too diffuse to meet U.S. electricity demand growth and, in the longer term, total electricity demand. In principle, the U.S. renewable energy resource base can meet national electrical demand many times over although significant technical and economic challenges remain. The case for renewably generated electricity brightens as renewable energy and energy efficiency technologies advance and the environmental, health, security, and other costs – including climate change impacts – of fossil-based energy become reflected in market prices. The chapter discusses impacts of fossil fuel-based generation, the renewable energy resource base, trends and advances in renewable energy technologies and costs, and limitations and impediments to renewable energy for electricity. The chapter also addresses policy options for mitigating negative impacts of electrical generation while promoting cleaner energy systems.

8.1. INTRODUCTION AND OVERVIEW

Plentiful and affordable electricity underlies a growing U.S. economy and improving quality of life. With coal and other fossil fuels providing the majority of America's energy for electric power generation along with predictions of continued growth in electricity demand (1.5% per year through 2030 [EIA, 2006]), some dismiss renewable energy sources as insufficient to meet the increasing demand for power. Many analysts and industry leaders also doubt that renewable energy can play a significant role in meeting global electricity needs, which one U.S. Department of Energy projection suggests will rise 2.6% annually through 2030, with most growth being in developing countries (EIA, 2005b).

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 171–199

Other skeptics argue that solar and wind power are “hopelessly impractical” and “are far too diffuse and intermittent to ever provide more than a small fraction of the energy needs of any major industrialized nation, let alone vast northern countries like Canada and the United States.” (EnviroTruth.org). Lee Raymond, the former chief executive officer of ExxonMobil, famously remarked in 1997 that “non-petroleum sources of energy” were merely “fashionable,” and that “with no readily available economic alternatives on the horizon, fossil fuels will continue to supply most of the world’s energy needs for the foreseeable future.” (Raymond, 1997) Such ideas have infiltrated the news media. One news commentator, for instance, referred to renewable energy as a “pipedream” with “dubious prospects.” (Milloy, 2004) The coal, railroad, and electric utility industry-supported Center for Energy and Economic Development is more circumspect but just as wary, stating that non-hydro renewable energy is “limited to a niche role for peaking power because it is an intermittent resource.” (CEED).

Yet, the resource base for wind, solar, and other renewable energy sources is large. Theoretically, American renewable resources could meet U.S. power demand many times over. Today renewable energy, mainly in the form of hydroelectricity, already provides about 9% of U.S. electric generation. That proportion is likely to grow significantly as the cost of renewable energy continues its decline, while at the same time the costs associated with fossil energy – including impacts on human health, the environment, and climate – become more apparent. The energy efficiency of our buildings and equipment is also likely to improve, curbing growth in power demand.

While America and the world are likely to continue to use fossil fuels to generate power for some time, the combination of renewable energy and energy efficiency can moderate and eventually reverse growth in fossil fuel-generated power. Over the long term, renewable energy can displace fossil energy to move our electrical and broader energy systems toward a sustainable path of meeting human needs by living off of nature’s income rather than depleting nature’s capital.

To explore such themes in greater detail, this chapter examines environmental impacts of current electrical generation and the need for cleaner, more environmentally sustainable energy sources and technologies. It provides an overview of the major categories of renewable energy as applied to electric power production, including potential, status, challenges, and limitations. And it ends with a discussion of policy issues pertinent to renewable energy and, more generally, cleaner energy and environmental sustainability. A recurring theme is the implicit subsidy fossil fuel energy systems receive when their impacts on public health and the environment are not reflected in energy costs, and the economic disadvantage this places on cleaner energy systems, including renewable energy.

8.2. WHY CARE? ELECTRICAL GENERATION ENVIRONMENTAL IMPACTS

Renewable energy is not preferable to fossil fuel energy for its own sake, and it is not free of environmental impacts. However, renewable energy systems usually offer environmental, including human health, benefits over most fossil energy systems.

Despite significant improvements in pollution controls and other environmental measures, fossil fuel derived electric power imposes significant costs beyond those reflected in utility bills.

Abt Associates, Inc., using methods developed for the U.S. Environmental Protection Agency (EPA), conducted a study estimating the health impacts of fine particulates ($PM_{2.5}$, particles smaller than 2.5 micrometers in diameter) resulting from U.S. fossil fuel-fired power plants.[1] The study estimated that such emissions are responsible for more than 23,000 premature deaths each year as well as nearly 22,000 hospital admissions, 26,000 hospital emergency room visits for asthma attacks, over 38,000 heart attacks, over 16,000 cases of chronic bronchitis, over a half-million asthma attacks, and over three million lost work days (Abt Associates, 2004).

In 2004, U.S. power plants, mainly coal-fired, emitted nearly 10.9 million tons (roughly two-thirds of national emissions) of sulfur dioxide (SO_2), a pollutant responsible for lake- and forest-damaging acid precipitation and a precursor to health-damaging particulates. Coal, oil, and natural gas fueled power plants also released over four million tons (20% of national emissions) of nitrogen oxides (NO_x).[2] NO_x is a major precursor of health-, crop-, and material-damaging ground-level ozone (a component of smog) and also contributes to acid precipitation as well as to nutrient pollution of bodies of water.[3] American coal-fired power plants released about 50 tons of mercury into the air in 2004, making electrical generation the largest anthropogenic emissions source for this neurotoxic element(EIA, 2006).

In addition, U.S. power plants emitted 2.25 billion metric tons of carbon dioxide (CO_2) in 2003, accounting for 39% of net U.S. CO_2 emissions (or 37% of net U.S. emissions of all greenhouse gases on a CO_2-equivalent basis) (EPA, 2005b). Thus, electrical generation is the single largest contributor to global warming potential of all U.S. industries.

Fossil fuel extraction, processing, and use also affect water and land resources directly. Of the over 1 billion tons of coal mined in the United States annually, roughly 70% comes from surface mines (EIA, 2005a). While U.S. surface mining operations are subject to mineland reclamation requirements, some practices – such as mountaintop removal operations in the Appalachians – have destroyed streams, disfigured landscapes, and increased flood, water quality, and other hazards to nearby residents and communities (Figure 8.1) (Appenzeller, 2006; Mitchell, 2006; Reece, 2006). Failing coal slurry impoundments, acid mine drainage, aquifer disruption, saline water from coalbed methane recovery, and miner occupational safety and health hazards (including deaths) are among the other impacts of fossil fuel reliance for power. In addition, most fossil fueled (and some biomass fueled) power plants use large amounts of cooling water, which is heated and released back into the environment, affecting aquatic life.

The foregoing is not a complete survey of fossil fuel-based electricity generation impacts. Nor is it meant to belittle important progress industry has made to control emissions and mitigate impacts. However, from killing streams to harming human health to being the major contributor of climate altering gases, our current electricity generation system imposes very high costs on human and ecosystem health. These

Figure 8.1. Mountaintop removal coal mining: Kayford Mountain, West Virginia (Vivian Stockman, Ohio Valley Environmental Coalition)

costs, borne by harmed individuals and society, are not reflected in utility bills and represent a very large subsidy to fossil fuels. Renewable energy combined with improved energy-use efficiency offer a path to environmentally and economically sustainable electricity.

8.3. U.S. ELECTRIC POWER PRODUCTION AND CAPACITY

Currently fossil fuels dominate the U.S. electricity generating system. Data from 2004 indicate that of almost 3,800 billion kilowatt-hours (kWh) of grid-connected American electricity, 53% came from burning coal. Natural gas and petroleum contributed 13 and 3%, respectively. Nuclear power provided 22% while renewable sources supplied only 9%.[4] (EIA, 2006). Hydroelectric power dominates the renewable category, with wind, biomass, geothermal, and solar accounting for only 2% of U.S. power generation (NCEP, 2004). (As a point of reference, the average American household consumed approximately 10,500 kWh in 2001. [EIA, 2005c]).

The U.S. electric power system can also be characterized in terms of generating capacity, which was roughly 900,000 megawatts (MW) in 2004. From this perspective too, fossil fuels dominate; 34% coal-fired steam, 14% other fossil fuel-fired steam, 14% combined cycle (in which natural gas or petroleum-based fuels are burned to run both a combustion turbine and a steam turbine), and 14% combustion turbines and diesel generators. Nuclear power plants account for 11% of U.S. generating capacity and renewable energy, mainly hydropower, 10%[5] (EIA, 2006).

The U.S. Department of Energy (DOE) Energy Information Administration (EIA), which provided these data in the *Annual Energy Outlook 2006* (EIA, 2006), also forecasted future electric power generation and generating capacity. Its reference case suggests 1.7% annual growth in renewably derived generation and 0.8% annual growth in renewable generation capacity during the years 2004 through 2030. While such growth would be significant, AEO 2006 forecasts for total electricity demand (1.5% annual growth) and fossil fuel-based generation (2.0% annual growth for coal) are of a similar magnitude. This would leave renewable energy in the same range of nine to 11% of total generation and generating capacity throughout the forecasted period. The scenario also forecasts a diminishing role for nuclear power, dropping to 19% of generation in 2015 and 16% in 2030, while coal grows to 60% by 2030 (EIA, 2006).

So, is renewable energy destined to remain a modest source of the nation's electricity? Are the skeptics right that renewable energy can fill only a niche role? Will coal remain king for the foreseeable future? Is carbon sequestration the only hope to slow and reverse electricity sector contributions to global warming?[6]

No – at least not necessarily. Forecasts in AEO, 2006 and from other sources should be viewed cautiously, particularly longer-term forecasts and scenarios. Future price changes, economic growth rates, technological advances, and changing policy measures are all uncertain and all affect electricity demand and the blend of fuels and technologies needed to meet it. For instance, increased natural gas prices led AEO 2006 to revise downward by 25% the amount of natural gas-generated power expected in 2020 as compared to the forecast made just a year earlier in *Annual Energy Outlook 2005* (EIA, 2005d).

Other analyses suggest significantly greater growth in renewable energy electricity supply and more moderate electricity demand growth due to greater energy end-use efficiency. For instance, the National Commission on Energy Policy (NCEP) expects that non-hydro renewable energy will grow to 10% of U.S. electric power generation by 2020 if the Commission's greenhouse gas cap-and-trade and increased research and development (R&D) policy prescriptions are followed (NCEP, 2004). In contrast, the business-as-usual scenario would leave non-hydro renewable energy at only 3% of total generation.

In 2000, a group from Oak Ridge and Lawrence Berkeley National Laboratories (the Interlaboratory Working Group on Energy Efficient and Clean Energy Technologies) developed business-as-usual, moderate, and advanced scenarios estimating electricity demand and production by fuel for 2010 and 2020. The moderate and advanced scenarios posited differing degrees of policy support to cleaner energy technologies, both renewable and non-renewable. These included, among others, tax credits, net metering (allowing on-site power generators to sell excess power back to their utility at retail rates), utility restructuring, R&D support, reducing SO_2 emissions allowances, and capping CO_2 emissions. Under the business-as-usual scenario, renewable energy contributes 10% (2 to 3% non-hydro) of U.S. electricity in both 2010 and 2020. In the moderate scenario, renewable energy grows to 12.5% (3.5% non-hydro) in 2010 and 13% (5% non-hydro) in 2020. The advanced scenario suggests 17% (8% non-hydro) and 18% (9% non-hydro) in 2010 and 2020, respectively. Both moderate and advanced scenarios suggest growing renewable energy implementation as well as moderated electricity demand growth due to improved energy efficiency (Interlaboratory Working Group, 2000; Brown et al., 2001).

The scenarios and forecasts above are not the only ones or necessarily the best ones. There are others, some more and some less optimistic about renewable energy. Forecasts and scenarios indicate what could be, not what will be.

A closer look at renewable energy technologies, potential resource size, and cost trends, as well as important challenges and limitations can help illuminate the opportunities and potential for renewably-derived electricity.

8.4. RENEWABLE ENERGY SOURCES AND RESOURCES FOR ELECTRICITY GENERATION

Other than nuclear and geothermal energy, all of our energy is ultimately solar. Through photosynthesis plants, algae, and some bacteria capture solar energy to form biomass, some of which is taken up by animals, fungi, and other bacteria. Coal, oil, and natural gas are ancient biomass transformed through geologic processes.[7] Hydropower is the result of the sun driving the cycle of evaporation and precipitation of water. Wind, ocean waves and currents, and ocean depth temperature differences (which can be converted into electricity through a technique called ocean thermal energy conversion) are products of the sun's rays differentially heating the Earth's surface, thus powering the planet's weather and climate. Tidal power comes from gravitational pull of the moon and sun.

The sections that follow discuss, primarily in the U.S. context, the potential, status, challenges, and limitations of principal renewable energy forms for production of electricity.

8.4.1 Solar

In considering direct use of solar energy (as opposed to wind, biomass, and other forms), there are two ways to produce electricity. One way is use of photovoltaic (PV) cells, sometimes called solar cells. The other approach is solar thermal, using mirrors to concentrate the sun's rays to heat a fluid to run a turbine or engine that, in turn, operates an electrical generator.

Photovoltaic cells (PVs) are almost entirely made from silicon and other semiconductor materials, and are frequently in the form of flat-plate modules that are mounted on roofs, canopies, or on separate mounts (Figure 8.2). Concentrating lenses are sometimes used to boost efficiency. Crystalline silicon (single-crystal or polycrystalline) PVs are the most common type sold. They typically offer higher

Figure 8.2. Roof integrated PVs and solar thermal panels on a coastal Maine residence (Solar Design Associates, Inc. and DOE/National Renewable Energy Laboratory)

efficiencies of converting sunlight into electricity (10–20%) than most alternative thin-film PV systems (usually amorphous silicon, though copper indium diselenide, cadmium telluride, and other materials may be used). Thin-film amorphous silicon efficiency also degrades over time. However, thin-film PVs are less expensive to produce than crystalline silicon PVs. Thin-film PVs can be made on inexpensive plastic, glass, and steel backings, allowing production of flexible PV roofing shingles; PV integrated into glass canopies, windows, and skylights; and other building integrated structures.

Research continues on improved materials, new materials, and better manufacturing processes. For instance, multi-junction PVs incorporate several types of PVs stacked together to absorb and convert into electricity a greater portion of the solar spectrum. Dye-sensitized PVs use inexpensive titanium dioxide rather than semiconductors while polymer or plastic PVs under development also offer a potential for low cost production. Nanotechnology advances may offer new materials and technologies for PVs.[8] As with other new technologies and materials, potential occupational health and environmental risks and hazards of nanotechnologies require assessment.

Solar thermal electricity can be produced by several means. One is a solar trough system, in which a reflective trough concentrates the sun's rays onto a pipe containing heat transfer oil. The hot oil is used to boil water into steam to run a turbine. Such plants may use natural gas as a supplemental fuel. The solar power tower concept uses a field of tracking mirrors called heliostats to concentrate sunlight onto a target containing either water – which is boiled directly – or molten salt – which boils water via a heat exchanger – to drive a turbine to generate electricity. The molten salt system allows some degree of heat storage. Another solar thermal electric approach is to have a mirrored dish focus sunlight onto a heat engine, such as a Stirling or Brayton cycle engine, that uses the mechanical energy of heated expanding air or other gas to drive an electrical generator.

Adequacy of the total solar resource is not in question. In principle, sunlight shining on the United States contains energy equivalent to 500 times U.S. energy demands (UCS, 2005). Using current PV technologies, an area of 10 million acres could provide all of the electricity used by the United States (NREL, 2004). Ten million acres is about 0.4% of the area of the United States, or about 7% of the 140 million acres of the United States covered by cities and residences. PVs mounted on rooftops, sides of buildings, over parking lots, along highways, and on other developed land could, in principle, provide national electricity supply without the need for additional land development.

Contrary to certain impressions, practical solar power is not limited to the sunniest locales, such as the desert Southwest. Cities in Arizona receive about 25% more sunlight than Kansas City, MO, which, in turn, receives about 25% more sunlight than Buffalo, NY (NREL, 2004). Even cloudy portions of the nation, such as parts of the Northeast and Pacific Northwest receive large amounts of useable solar energy, though the required land area and cost to generate a given amount of electricity would be greater than in sunny climates. Germany, with a climate closer to, say, Buffalo or Seattle than Phoenix or Las Vegas, and with an average solar resource per square meter about half that of the United States, has a rapidly growing solar power capacity. By the end of 2004, Germany had 700 MW peak PV capacity installed as a result of its "100,000 rooftops" program (Aitken, 2005).

In practice, PVs and solar thermal technologies will not provide 100% of U.S. generation any time in the foreseeable future. However, their contributions can grow, thereby lessening the environmental impacts of our energy systems, providing a diversity of energy sources, and enhancing the reliability and security of our electrical supply.

Solar power is limited by the fact that the sun shines only during the day and is affected by weather conditions. Energy storage for electricity is constrained by available sites (for pumped hydroelectric storage in reservoirs or compressed air storage in caves), cost, and technological immaturity (for instance, batteries, flywheels, superconducting materials, and hydrogen production). However, peak power demand is typically during the day when the sun does shine so solar power is most available when electricity is usually most needed and most valuable.

Variability of solar-generated electricity due to weather (for instance, cloud cover) also affects its dependability and value. While critics point to the intermittency of solar as well as wind power as a problem, one should note that electric utilities are adept at handling significant variations in electricity supply and demand already. They use weather forecasts to plan on power needs for heating, cooling, and lighting. Forecasts and planning tools can also estimate solar (and wind) power output. They routinely handle supply and demand changes as large industrial customers and a myriad of smaller business and residential customers turn on and off electricity-using devices.

Cost remains the biggest impediment to solar power, both PV and solar thermal. The cost of PV modules have decreased precipitously from around $100 per watt of capacity in 1970 to the $4–5 range now; dropping about 20% with each doubling of total PV production (Solarbuzz, 2006a; SEIA). Still, PV-provided power frequently costs greater than 20 or 30 cents per kWh (Figure 8.3). This is double or triple retail electricity costs in much of the United States and an even greater multiple over generation costs for the lowest cost coal-fired units.[9] (Solarbuzz, 2006b). Currently, PV is competitive in limited contexts. For instance, in parts of the United States, peak power costs on hot summer days can exceed the 20 to 30 cent per kWh range. PVs can moderate a building's electricity costs by reducing the two components of an institutional or commercial electric bill, energy consumption and peak power demand. Utilities can take advantage of PVs at customer sites or utility substations and distribution nodes to avoid costly upgrades to transmission equipment for meeting peak demand. Further, PVs combined with battery storage are often cost-effective today for off-grid applications, where extension of grid connected electric lines impose high cost. And PVs with battery storage – as well as other distributed energy technologies – may meet premium power needs as a back-up or complement to the electric grid for high priority and sensitive power demands.

Improved technologies and manufacturing economies of scale should drive PV costs down further. Various policy mechanisms have been used in the United States and abroad to promote economies of scale. Germany's 100,000 rooftops program

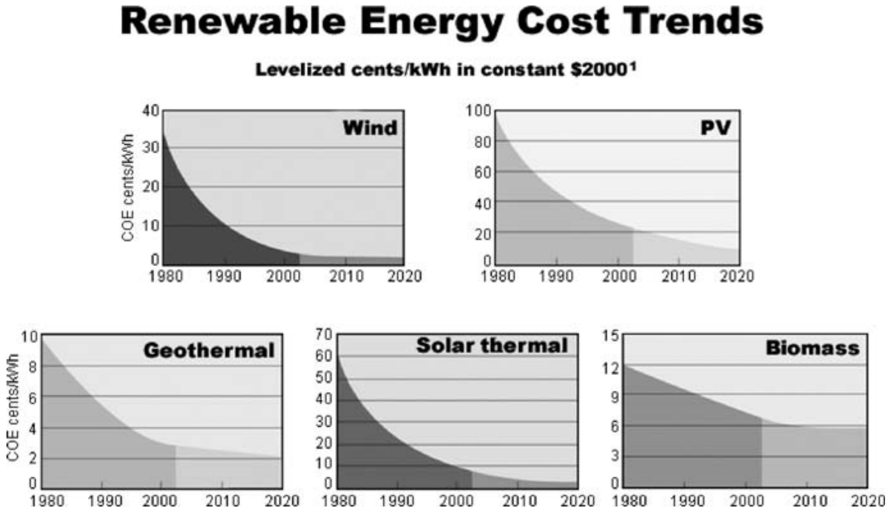

Figure 8.3. Renewable energy cost trends (NREL Energy Analysis Office [www.nrel.gov/analysis/docs/cost_curves_2002.ppt]). These graphs are reflections of historical cost trends not precise annual historical data. Updated October 2002

was mentioned above. New Jersey and California are among the U.S. states with aggressive solar energy incentives[10] (See last section of this chapter for more on renewable energy policy issues).

8.4.2 Wind

Like solar power, the American wind resource can, in principle, provide more power than the United States consumes: 10,000 billion kWh, over twice U.S. demand, according to some estimates (DOE, 2004). North and South Dakota, Kansas, and Texas could each produce over 1,000 billion kWh yearly, or one-quarter of U.S. annual use, based on land classified as wind class 3 or better while still omitting environmentally sensitive and developed land (Figure 8.4).[11] (AWEA, 2006c). Another calculation suggests that four million 500-kW wind turbines spaced 500 meters apart placed on 10% of the land most favorable for wind power could also meet U.S. electricity demand (Weinberg and Williams, 1990). An update of this scenario could posit larger (1–2.5 MW) wind turbines at fewer sites. Also, the wind power potential is even greater when offshore resources are included.

The amount of land required in these scenarios may seem vast but is moderated by the fact that land – or water surface – used for wind power is available for multiple uses. Wind turbine structures and service roads occupy only three to 5% of the surface area of a wind farm (DOE, 2004). Land-based wind farms are often located on farms and ranches, providing landowners with additional royalty or lease

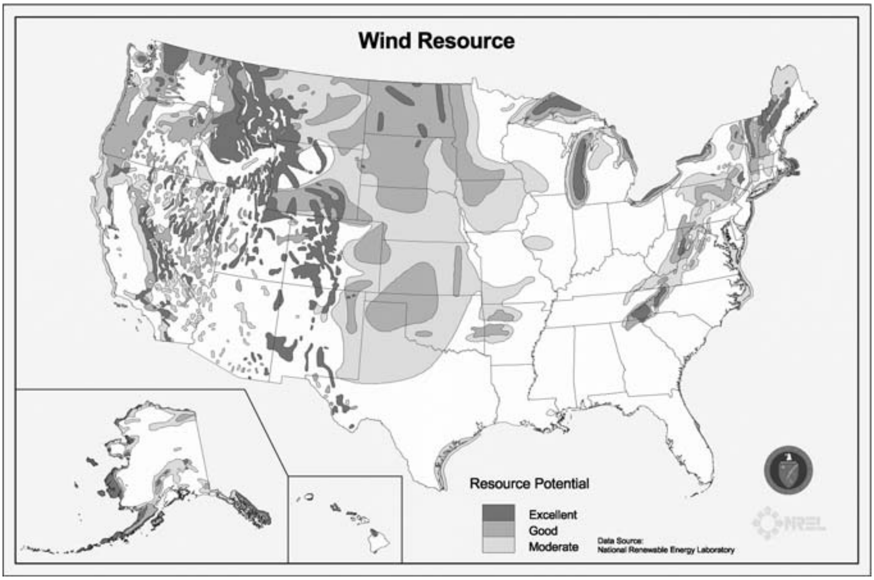

Figure 8.4. U.S. wind power resources (DOE/National Renewable Energy Laboratory)

income (Figure 8.5). In Pennsylvania, some wind power installations are on former coal mine lands, helping bring such land back to productive use. Offshore, waters surrounding wind installations could still be used for fishing and recreation. They offer no greater hazard to navigation or other uses than do offshore oil and gas installations that dot the Gulf of Mexico and other coastal areas (except that no oil spills will occur).

It is true that the richest American wind resources – in the Northern Plains and Rocky Mountains, for instance – are far from the country's main electrical loads. Large long-distance electrical transmission investment would be needed to bring such power to principal American population centers. However, there are significant resources available near many well-populated parts of the Northeast, Mid-Atlantic, Great Lakes, Texas, and West Coast. Offshore resources, though more costly to tap than many onshore resources, are also significant and often close to major population centers.

Costs of wind power have dropped dramatically, from the eight to 12 cents (year 2,000 dollars) per kWh range in 1990 to three to five cents currently for suitable sites (Figure 8.3) (DOE, 2004). Improved design of blades and other components, greater experience in siting and project development, and larger scale machines (often over 1 MW) enhance economic performance and reliability. Wind power can be commercially competitive for grid power, though it remains more expensive than the cheapest coal-fired power generation (if one does not include environmental and health costs not included in electricity prices). Smaller wind turbines, sometimes

Figure 8.5. Wind farm with 1.5 MW turbines at Kimball, Nebraska. (Tennessee Valley Infrastructure Group Inc. and DOE/National Renewable Energy Laboratory)

combined with solar PV, find use in isolated locations and for peak and supplemental power applications.

It is unlikely in the foreseeable future that wind power will provide all or a majority of U.S. power needs by itself. Instead it can make a large contribution to the national generation mix; Battelle Pacific Northwest Laboratories estimates that it is realistic to meet 20% of U.S. electricity needs with wind (AWEA, 2006c). For comparison, the German state of Schleswig-Holstein derives nearly 25% of its power from the wind. Denmark derived 21% of its electric power from the wind in 2004 (EWEA, 2005).

Wind power critics say that because winds vary, wind power is unreliable and must be backed up by conventional power operating continuously to assure reliability should the wind die down. Such views greatly overstate the case. At low penetration levels, such as below 10% of generation, variability of wind resource has modest impact on the electrical grid. Electric utilities routinely manage variability as customers turn on and off power consuming devices and respond to varying weather with heating, cooling, and lighting equipment. Managing modest changes in power supply is not different. As noted previously in the solar energy discussion, power utilities and transmission organizations use weather forecasts and other data, tools, and analyses to predict power demand and can use these to predict wind and solar generation. At higher levels of wind power penetration, as in parts of Germany and Denmark with greater than 20% wind power, electric grid operators do indeed need to be more adept in predicting and adjusting for both power supply and demand.

In a diverse integrated power grid, consisting of various generators (including distributed power at customer sites) as well as "demand response" measures to intelligently control loads, concerns about higher wind power penetration may be mitigated. If wind turbines are geographically dispersed and integrated into the grid, their aggregate output will be less variable than that from a single wind farm. It is unlikely that the wind will stop at all generators simultaneously; some or most are likely to provide some power. A typical wind turbine generates power 65–90% of the time, though often at below its nameplate capacity, leading to a typical capacity factor of 25–40%[12] (DOE, 2004; AWEA, 2006b). Some point to a capacity factor of 18–20% (White, 2004). Also, each wind turbine is a relatively small generator compared to fossil fuel and nuclear units. Managing variable but predictable wind power is less problematic than dealing with unplanned outages at major fossil and nuclear units or responding to damage at significant transmission facilities, as occur on occasion. Further, wind power developers naturally will try to develop sites with the best wind resources, meaning sites that are most consistently windy.

In Western Denmark, where wind power provides 25% of electrical generation, the transmission system operator wrote the following in its annual report:

> Since the end of 1999 – so in just three years – wind power capacity in the Jutland-Fyn system has increased from 1,110 MW to 2,400 MW. In installed capacity that is twice the capacity of the 'Skydstrup' power plant near Aarhus. Seven or eight years ago, we said that the electricity system could not function

> if wind power increased above 500 MW. Now we are handling almost five times as much...[W]e are ready to handle even more, but it requires that we are allowed to use the right tools to manage the system.
> (EWEA, 2005)

However, critics suggest that Denmark's wind power success is overstated and depends on links to Norwegian and Swedish hydropower systems, which are said to offer flexibility to absorb excess Danish wind power output (White, 2004).

The European Wind Energy Association (EWEA) concludes that regulatory issues are bigger impediments to significant wind power penetration than technical issues. One issue is barriers to cross-border power transmission, since integration of wind power over a geographically wide grid would buffer locally variable wind power output. EWEA also claims as barriers excessive technical requirements imposed by dominant vertically integrated power companies and low liquidity of European wholesale power markets (EWEA, 2005).

Another concern about wind power is its effects on wildlife, primarily birds and bats although marine impacts of offshore development are sometimes raised. Early experience at the Altamont Pass in California led to significant concerns about bird collisions. Numerous raptors were killed there. The Altamont Pass case is exceptional in terms of location and because of its early development, before bird avoidance features were incorporated in wind turbine design. Improvements in equipment design and siting have reduced avian collisions to relatively low levels (NWCC, 2004; AWEA, 2006a). The U.S. Fish and Wildlife Service published an estimate of 33,000 annual U.S. bird deaths from wind turbine collisions compared to 60 million from cars, several million from communication towers, and hundreds of millions from buildings (USFWS, 2002). The wind equipment improvements include smooth tower design to discourage nesting and slower blade speeds. Lighting, especially during foggy weather, has contributed to bird deaths at communication towers and other structures, including at least one incident at a wind power facility. For these structures, improved lighting may reduce bird mortality while still meeting Federal Aviation Administration requirements for aviation safety. Significant bat kills at ridgeline wind turbines in parts of Pennsylvania and West Virginia led the American Wind Energy Association, Bat Conservation International, U.S. Fish and Wildlife Service, National Renewable Energy Laboratory, and others to form a Bats and Wind Energy Cooperative to study this problem and identify ways to prevent or minimize threats to bats (Bat Conservation International).

As noted, for perspective, people kill many more wild birds through other means. Hundreds of millions to billions of birds are killed in the United States annually from collisions with buildings, towers, smoke stacks, power lines, and other structures as well as vehicles – not to mention birds killed by cats. In one publicized event 27 birds were found killed at the Mountaineer wind power facility in West Virginia due to a light left on overnight at a substation (subsequently turned off at night to avoid a repeat incident). Yet, 3,000 birds were killed in collisions at a Florida coal-fired power plant in a single night during fall migration (American Bird Conservancy, 2004). Also, in assessing wildlife impacts of wind projects the proper comparison is not between the presence and absence of a project as it is between the project and an alternative means of providing energy services. How many birds, bats, land mammals, amphibians, reptiles, fish, and other organisms perish from strip mining coal, collisions with power plant structures, in power plant cooling water intakes, from hot water discharges, from mining limestone for pollution control scrubbers, and as consequences of acid rain, climate change, and other pollution effects? Coal mining mountain top removal/valley fill operations have destroyed 380,000 acres of mature high quality forest in the Appalachians of Kentucky, Tennessee, Virginia, and West Virginia over the last decade and a similar area may be mined in the next decade (American Bird Conservancy, 2004). Still, wind power impacts on wildlife require more research, great care in siting and design, and perhaps additional attention to operational practices, such as better control of lighting or feathering blades and shutting down generation at certain sites during important migratory periods for birds and bats.

Wind power projects also have significant scenic impacts, which have engendered significant opposition in some communities. Though again, one should compare wind with other energy sources.

8.4.3 Biomass, Landfill Gas, and Waste-to-Energy

Next to hydroelectricity, biomass is the largest source of renewable electric power in the United States. Biomass energy is a broad category encompassing energy derived from agricultural, forestry, and plant- or animal-derived industrial wastes, as well as specially produced energy crops, landfill and sewage treatment gas, and municipal solid wastes (MSW).[13]

Biomass energy usually comes from directly burning the resource (for instance, MSW-burning waste-to-energy plants, landfill gas energy facilities, and wood-fired power plants) or co-firing it with fossil fuels (for instance, supplementing coal with wood or landfill gas). Biomass can frequently be digested (as normally occurs in a landfill but may be purposely done in a digester) or chemically processed (via pyrolysis and similar approaches) to produce a gaseous fuel. And some can be processed into liquid fuels such as alcohols and biodiesel, usually for motor vehicle fuels rather than electric power production.

A DOE analysis estimates that 590 million wet tons of biomass (agricultural wastes, energy crops, forestry residues, urban wood waste, and mill residue – but not including other wastes or landfill gas) are available annually in the United States. Of this, only 20 million wet tons (equivalent to 14 million dry tons), sufficient to supply 3,000 MW or about 0.3% of U.S. electric power production capacity, are available at a price of $1.25 per million British thermal units (Btu), about the price ($1.23 per million Btu) of coal in 2001 (Huq). Thus, at these prices only about one-thirtieth of the theoretical biomass supply would be economically available. More biomass would be available at higher prices. Transportation costs are a major factor affecting supply (See Figure 8.3 for cost per kWh trends).

Another analysis, performed by Oak Ridge National Laboratory for DOE and the U.S. Department of Agriculture, projects that U.S. farm and forest land (excluding environmentally sensitive areas) could sustainably produce 1 billion dry tons of biomass annually for energy while still meeting food, feed, and export demands. This amount could displace 30% of U.S. petroleum consumption but could also be applied to electric power generation or other energy needs. However, the study's conclusions depend on generous assumptions of increased grain yields, production acreage, and collectibility of biomass materials (ORNL, 2006).

A global macro-estimate of biomass potential suggests that a roughly 50% increase in human exploitation of biomass beyond existing food, feed, fiber, and other material uses could displace all fossil fuel consumption at current rates (Dukes, 2003). Such an expansion in biomass use would entail significant environmental consequences.

Not surprising, most biomass electric power production occurs in the pulp and paper industry, which has a ready source of materials, including wastes that must otherwise be disposed, and a large demand for both heat and electric power. There is considerable scope for livestock production, food processing, and other industries to recover useful power and heat from organic wastes in order to simultaneously meet energy needs and treat wastes. Sewage treatment plants, surprisingly, infrequently generate power from gas evolved by anaerobic sewage treatment despite having high electric and heat loads suitable for combined heat and power production.

MSW waste-to-energy incineration plants also take advantage of readily available fuel supply. However, proposals for such facilities generally engender significant opposition primarily due to concerns about emissions, which can contain dioxins, furans, mercury, and other toxic substances. Properly operated facilities meeting maximum available control technology (MACT) standards control emissions to a very high degree. A few rural backyard burn barrels may present a larger dioxin hazard than a significant urban waste-to-energy plant (Lemieux, 1998).

Landfill gas is a growing source of power. Large landfills are required to collect and destroy gases to reduce explosive hazard and to control volatile organic compound, hazardous, and odorous emissions. Frequently these gases are flared but they can be captured for direct use in heating, processed and injected into natural gas lines, or used for electric power generation (with or without recovery of cogenerated heat). Greenhouse gas emissions are also reduced by burning landfill gas since methane has about 21 times the global warming potential as the same mass of carbon dioxide (plus power generated from landfill gas may displace fossil fuel-based power generation). Landfills are the largest human-made source of methane emissions (34%) in the United States. The EPA Landfill Methane Outreach Program estimated that at the end of 2004 there were 380 active landfill gas energy recovery projects in the United States (not necessarily using all recoverable landfill gases from those landfills) and 600 good candidate landfills available (EPA).

There is competition for use of land and biomass resources. Fuel production would compete with food, feed, fiber, and certain industrial chemical markets. Much of the emphasis on biomass energy R&D and project development is for liquid fuels to substitute for gasoline and diesel fuel. While some of these fuels may be used for electric power production, most are or will be marketed for vehicle fuels. Soy and other oil crops can be processed into biodiesel (with by-products going to other markets) as can animal fats and greases. In the United States, ethanol is made from fermenting corn although other starchy and sugar-containing materials can be used, as evidenced by Brazil's extensive sugarcane-based ethanol industry and, of course, millennia of alcoholic beverage production. Ethanol production may be on the verge of significant growth. Improved enzyme production and biochemical engineering is leading toward a "cellulosic" ethanol industry; opening corn stover, rice straw, switchgrass, woody materials, and other cellulose rich materials to ethanol production.

The impact of economically and technically viable cellulosic ethanol production on biomass-based electricity generation would be further competition for biomass feedstock and land. Wood and switchgrass have been used in proportions of up to 15% to co-fire coal-fired power plants. Wood-only fueled power plants also exist. Switchgrass – grown and harvested like hay – can improve marginal farmland and enhance wildlife habitat while providing additional farm income when sold for energy (Figure 8.6). Fast-growing poplar and willow are also being investigated as

Figure 8.6. Iowa switchgrass (Warren Gretz and DOE/National Renewable Energy Laboratory)

dedicated energy crops. Cellulosic ethanol could become an alternative to direct combustion as a market for such energy crops.

Like other combustion-based processes, biomass-fired power generation creates emissions and other environmental impacts. When co-fired with coal, biomass reduces SO_2 relative to coal alone. However burning wood, crop wastes, animal wastes, black liquor, digester gases, and other types of biomass release NO_x, particulates, and, potentially, other pollutants. But those can be mitigated – at a cost – with pollution controls. Gas derived from digesting biomass is generally cleaner burning than solid biomass fuels. Indeed, flaring of landfill and sewage digester gases is an effective and standard method of treating volatile and odorous compounds. In terms of greenhouse gases, biomass utilization can be "carbon neutral" if new growth matches combustion.

Like other agricultural and forestry production, increased biomass use can significantly affect land, water resources, and wildlife for better or worse depending on practices followed. Crop residues removed from the land for energy rather than left in fields deprive soil of organic matter and affects soil structure. Mechanical tillage, fertilizer use, and pesticides impose environmental costs. However, switchgrass and some tree-based biomass crops do not require tillage after initial establishment and may require fewer chemical and energy inputs than field crops. Such biomass crops can help restore degraded and marginal farmland, protect water resources (for instance, as part of Conservation Reserve lands), and provide wildlife habitat.

8.4.4 Geothermal

In principle, geothermal energy can be tapped from anywhere in the United States and represents an almost limitless resource (at least compared to current and foreseeable scales of human activity). But in practice it is generally not feasible unless sufficient heat is near the surface. Alaska, Arizona, California, Hawaii, Idaho, Montana, Oregon, and Washington are states with the best geothermal resources. Geothermal power is most easily accessible from formations containing steam or hot water, which can be used to run a steam turbine to generate electricity. It is not yet economically feasible to extract power from hot dry rock formations.

As of 2003 there were about 22 geothermal power plants with 2,300 MW of capacity operating in the United States. Identified resources (containing steam or sufficiently hot water) are estimated at 23,000 MW (around 2% of national generating capacity) and there may be as much as five times this amount not yet discovered (Kutscher, 2000). If energy extraction from hot dry rock formations – requiring deep injection of water and recovery of steam – can be made economically viable, geothermal resources could provide all U.S. electrical power needs for many thousands of years.

Unlike the sun and wind, geothermal energy resources can be locally depleted. Closed loop systems and water injection can replenish water or steam, though over time heat may be depleted. Properly managed geothermal plants can provide power effectively for 50 or more years but several centuries may be needed before the local resource recovers.

An advantage of geothermal over other renewable power sources is its consistency. Unlike wind and solar, it is little affected by weather. Geothermal plants can meet baseload power generation needs 24 hours a day with very high availability rates, often 90% or better (in comparison with 75% for many coal units) (DOE, 2006a).

Also, at suitable sites, geothermal power is economically competitive. The Geysers plant in California sells power in the 3 to 3.5 cents per kWh range while new plants may be expected to produce 5 cents per kWh (Figure 8.3) power. As with solar and wind power, much of the cost is upfront capital with no fuel and low operating costs. New plants can be expected to cost $2,500 per installed kW (DOE, 2006a).

Some geothermal plants may produce modest emissions of sulfur-containing gases and CO_2, smaller than natural gas fired plants. Binary type plants are closed cycle and do not release significant gaseous and liquid emissions. Dissolved minerals are typically reinjected into the geothermal reservoir along with excess water well below groundwater aquifers that may be used for drinking and irrigation. Some plants that do produce sludge have to dispose those materials or find beneficial uses (e.g., recovery of sulfur, zinc, and silica) (DOE, 2006a).

8.4.5 Hydropower

Hydropower is the largest current source of renewably generated electricity, accounting for about 7% of U.S. generation and about 80,000 MW of generating capacity at over 2,000 sites. A DOE assessment identified 5,677 other sites with undeveloped capacity for 30,000 MW.[14] (DOE, 2005a) The limited number and capacity of undeveloped sites and environmental impacts of dams constrain opportunities for significant new utility scale hydropower.

Dams impede fish migration, a problem sometimes mitigated with fish ladders. They harm or kill fish drawn into turbines, inundate land, and impede natural cycles and variations in river flow, temperature, and sediment. In recent years, some dams have been breached to restore rivers to a more natural state. Also competing water demands, including navigation, irrigation, and protection of aquatic habitat, have scaled back hydroelectric generation in some regions. DOE projects that the hydropower share of national generation will decrease over the next couple of decades.

Run-of-the-river hydropower plants avoid the environmental problems associated with fully damming rivers. Such plants divert a portion of a river's flow to turbines to generate power, leaving most water to flow naturally in the river. This can be done at a very large scale, as at Niagara Falls, or at small scales, including micro hydro projects below 22.5 kW, suitable for individual homes and small businesses.

Another newer approach to hydropower as well as ocean power development is called kinetic or free-flow hydropower (Figure 8.7). This approach employs turbines

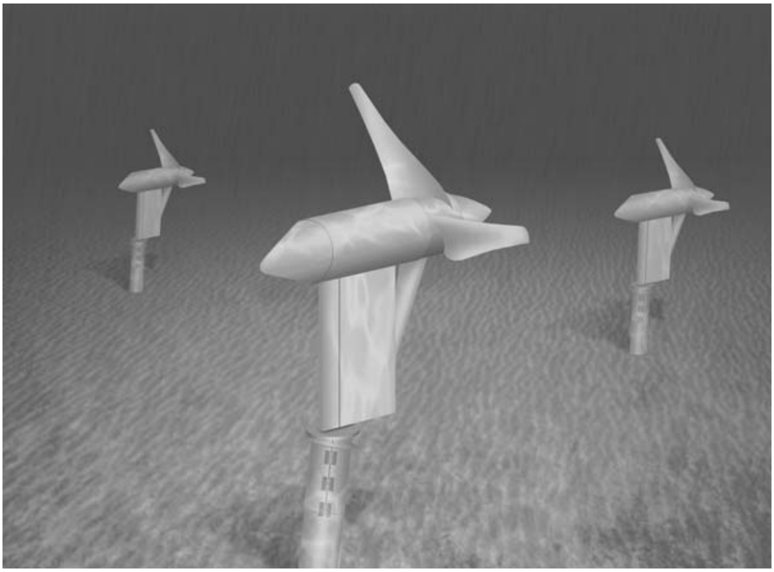

Figure 8.7. Axial-flow rotor turbine kinetic hydropower system (KHPS) for in-stream/in-channel capture of hydro, tidal, or ocean current energy (John Wuilliez, Ripe Studios/Courtesy Verdant Power, LLC)

anchored or mounted in-stream to generate electric power from river flow, canal flow, ocean currents, or tides without requiring dams, impoundments, or water diversion. One developer of this technology, Verdant Power, estimated a potential for 12,500 MW in the United States and 250,000 MW globally. The company's first project is to install, with New York State Energy Research & Development Authority support, an array of tidal turbines on the bottom of New York City's East River to capture up to 10 MW. The East River (really a salt-water channel linking New York Harbor, Long Island Sound, and the Harlem River) may have a 40 MW tidal power potential at four sites according to Verdant Power (Verdant Power).

The Department of Energy is assessing the potential for low-head (less than 30 feet of standing water height), low-power (under 1 MW) resources. The department also does R&D to reduce environmental impacts of hydropower and improve performance and efficiency of existing hydropower facilities.

8.4.6 Ocean Energy

Ocean energy resources include wave power, tides, and currents, and the energy capture potential of temperature differences between deep and shallow tropical waters (ocean thermal energy conversion – OTEC). These are potentially vast sources of energy but face major cost and technological challenges. Also they can raise significant environmental and siting concerns.

Both offshore and on-shore installations can capture wave energy. Some estimate a 2 million MW global potential with rich U.S. resources along both northwestern and northeastern shores. Pacific Northwest resources could produce 40 to 70 kW per meter of coast, which translates to 40 to 70 MW per kilometer or 67 to 117 MW per mile (DOE, 2005c).

Offshore installations in deep water (usually over 40 meters depth) capture energy from the bobbing motion of waves. There are several configurations for on-shore capture. In the oscillating water column approach, water entering and exiting steel or concrete structures compresses and decompresses enclosed columns of air to turn a turbine. The tapered channel or "tapchan" system is limited to sites with cliffs – waves push water up a narrowing tapered channel into a reservoir built atop a cliff. Water flowing from the reservoir back to the sea turns a turbine. Pendular devices capture energy from back-and-forth motion, as in the flapping of a hinged lid on a box that is open to the sea on one side. The shore-based wave power systems require significant construction and may affect sediment flows and sea life. They also have scenic impacts.

There are several ways to capture tidal energy. Kinetic or free-flow turbines discussed previously capture energy from tides and ocean currents without construction of barriers that impede flow, possibly disturb sea life, and may affect navigation. Such turbines act like underwater wind turbines, but the greater density of water means that shorter blade lengths are needed to capture a given amount of power. For instance, a 15 meter diameter free-flow turbine may capture as much energy as a 60 meter diameter wind turbine. Other tidal energy capture methods require construction of barriers. A barrage or dam detains water then releases it to generate power when there is an adequate difference in water level. Alternatively, a tidal fence placed across a channel generates power as tidal flows spin turnstile type devices. Areas suitable for dams/barrages are limited and such structures impede sea life and disturb sediment flows. Tidal fences may affect sea life and obstruct navigation (DOE, 2005b).

Ocean thermal energy conversion (OTEC) offers great theoretical potential but is the most technically and economically challenging of ocean energy sources. The technology extracts power from the difference in temperature (20 °C or 36 °F) between warm surface water and cold deep water. Suitable sites are limited to some tropical coastal areas with close access to depths of greater than a mile. Warm surface water evaporates a low boiling-point chemical such as ammonia (closed system) or is itself evaporated in a low-pressure vessel (open system) to create a vapor that turns a turbine. Large pipes bring cold water up from great depths to condense the vapors. In the closed system, ammonia or other fluid is reused. The water condensed in the open system is free of salt; so fresh water is a useful product. Hybrid systems incorporate features of both the closed and open configurations. The pumping of deep cold water brings up nutrients, which can raise fisheries productivity but may have other impacts on biota. Researchers have demonstrated OTEC at a pilot scale in a number of locations, including 250-kW closed cycle and

50-kW open cycle systems at the Natural Energy Laboratory at Keahole Point, HI (DOE, 2006b). However, DOE does not currently support OTEC R&D.

All ocean energy power generation technologies face considerable economic and technical challenges. Some will likely require additional environmental impact assessment and care in siting, construction, and operation to mitigate potential negative environmental impacts.

8.5. THE PATH FORWARD

Despite considerable progress, the biggest impediment to greater use of renewable energy for electric power production remains cost. Technological advance continues to improve the economic and technical performance of various renewable energy technologies.

Other impediments also inhibit diffusion of renewable energy technologies. These include, among others, utility interconnection procedures that disadvantage renewable power generation; poor or nonexistent net metering rules in most states; utility planning and tariff-making that pass along fuel costs to customers but ignore the fuel-free price stability of some renewable energy forms; non-recognition or undervaluation of onsite renewable power generation to reduce peak demand; zoning, siting, and homeowner association restrictions; and large explicit and implicit subsidies to fossil and nuclear power.

Some of these institutional and regulatory hurdles arise from the decades-old dominant electric power paradigm that emphasizes centralized power generation and transmission by monopoly utilities under the regulatory purview of utility commissions. While utility restructuring efforts in many states may be changing the playing field, electric utilities and utility regulators are comfortable with the business and technology of fully dispatchable fossil fuel, nuclear, and large hydropower units. They, in many cases, are not so comfortable with and may sometimes be hostile to or dismissive of distributed power (fossil and renewable), energy end-use efficiency, and alternative renewable energy sources.

The myth of renewable energy inadequacy reinforces the bias that fossil, nuclear, and large hydropower are “hard” businesses and technologies while efficiency and renewables are the “softer” paths favored by idealists, environmental “extremists,” anti-capitalists, and the like. This, despite considerable investments in renewable energy by BP, General Electric, Sanyo, Sharp, Siemens, Shell, and other paragons of mainstream business along with the growing number of renewable energy entrepreneurs, venture capitalists, and angel investors motivated by profit.

As previously noted, renewable energy is not desirable for its own sake as it is for reduced environmental and health impacts compared to other energy sources. The best way to reduce these impacts is to make those who create pollution, waste, and other environmental hazards pay for them, either by directly preventing, controlling, and cleaning up the damage or by paying compensation for negative health and environmental consequences. This is also known as the polluter pays principle – those who create pollution should pay for its impacts, not taxpayers, society in general, or the victims harmed. By "internalizing" these "external" environmental costs, users of dirtier energy forms and technologies will have to pay more, which makes improved energy efficiency as well as cleaner energy – whether fossil or renewable – more economically attractive.

A difficulty with fully implementing the polluter pays principle (beyond the obvious political challenge of imposing costs on certain powerful industries) is that many health and environmental impacts are uncertain and hard to monetize. How many dollars of damage does a ton of CO_2 cause via global warming? What is the dollar cost of a ton of NO_x's contribution to asthma attacks, to nutrient loading of coastal waters, to smog damage to crops, or to acid rain damage to lakes and forests? However, we know these costs are not zero and we know – as illustrated in earlier parts of this chapter – that current levels of environmental controls required in the United States still allow large amounts of health impact and environmental damage and do not address global climate change.

There are several approaches to internalizing environmental costs that can promote renewable energy. And there are several other policy approaches to promote renewable energy. Among these policy tools are:

- Command-and-control regulations
- Pollution caps and tradable pollution allowances (cap-and-trade)
- Environmental fees or taxes
- Renewable portfolio standards
- Renewable energy subsidies
- Renewable energy R&D

Command-and-control is the traditional regulatory approach. It requires plants to achieve specific levels of pollution control and often specifies particular equipment and practices. Such regulations helped achieve significant power plant emissions reductions in the past. Tougher pollution standards would tend to increase the costs of using dirtier fuels and technologies relative to cleaner fuels and technologies, including renewables. However, command-and control regulations tend to lack flexibility or incentive for going beyond specific regulatory requirements. They do not do a good job of channeling market forces to achieve the most cost-effective results. Increasingly tough command-and-control rules for power plants may still be most appropriate for certain toxic pollutants that may have significant nearby effects but for pollutants whose impacts are regional, national, or international in scale, such as SO_2, NO_x, and, prospectively, CO_2, cap-and-trade approaches may be more cost-effective. For fossil fuel extraction processes, command-and-control regulations impose standards for operations and restoration of minelands and oil and gas fields.

Under a *cap-and-trade system* allowances are issued to permit some maximum amount of emissions.[15] Allowances may be allocated by auction, allotted based on past emissions, or a combination of the two. Over time the number of allowances available may be reduced to lower overall emissions. While there may still be some base level of command-and-control regulation in force, power plants would have the flexibility to meet their requirements by strengthening pollution controls, using cleaner fuels, reducing operations, or buying excess allowances from others who have achieved greater reductions than would otherwise be necessary. The U.S. SO_2 cap-and-trade system under the Clean Air Act Amendments of 1990 is credited with achieving greater emissions reduction at lower cost than would have been accomplished through command-and-control (Burtraw and Palmer, 2003).

Cap-and-trade is often suggested as the most feasible means to regulate CO_2. The Kyoto Protocol, which the United States did not ratify, allows international trading so that firms can buy CO_2 reductions elsewhere if they are cheaper than at home. A number of Northeastern U.S. states have developed a Regional Greenhouse Gas Initiative that includes a multi-state cap-and-trade system for CO_2 (RGGI, 2006). The National Commission on Energy Policy recommends a national cap-and-trade system for CO_2, as have some bills proposed to Congress (NCEP, 2004). The Commission recommendation includes a provision allowing power plants to buy additional allowances at a set price if capped allowances become too expensive. This would provide an economic safety valve to prevent the possibility of excessive cost and disruption to power supplies while still providing significant incentive for energy efficiency and renewable energy.

Environmental taxes or fees are charges for emissions, effluents, wastes, or other environmental insult. Revenues can be applied to pertinent environmental and energy programs. Or they can be used for general revenue, perhaps with corresponding reductions in income and other taxes to achieve revenue neutrality (i.e., no net tax increase) and to help move the tax base more toward taxing “bads” (e.g., pollution and waste) rather than “goods” (labor, savings, and investment). U.S. power plants and other facilities requiring major source permits under the Clean Air Act pay an annual fee – $38.78 per ton in 2004 – for SO_2, NO_x, volatile organic compounds, and particulate matter emissions. However, the fee, whose purpose is to fund permitting programs, is capped at 4,000 tons for each pollutant, thus providing no emissions reduction incentives for utility and merchant power plants, which generally pollute at much higher rates. Fifteen states and the District of Columbia have “system benefit charges” or “public benefit fund” charges imposed on electric bills to provide money to subsidize energy efficiency, renewable energy, and other clean energy options (DSIRE, 2006). Carbon fees have been proposed as a mechanism to attack CO_2 emissions, either as a stand-alone charge or, as recommended by the National Commission on Energy Policy, as a backup or safety valve to a cap-and-trade program.

Twenty-two states and the District of Columbia have *renewable portfolio standards* (RPS) that require electric utilities to derive a certain proportion of their electric power from renewable sources, either directly or from other power generators[16] (DSIRE, 2006). The typical RPS includes a timeframe over which the required renewable energy proportion is increased. An RPS may have a tradable allowance component that allows utilities to trade in renewable energy certificates (also called green tags) that certify delivery of renewable energy to the electric grid. An attempt to include a federal RPS in the Energy Policy Act of 2005 failed. An RPS acts as an implicit tax on fossil fuels and is a subsidy to renewable energy. An

RPS, such as may be applied nationally, could include a price cap as a safeguard to limit potential cost increases.

Renewable energy subsidies include federal renewable energy tax credits authorized under the Energy Policy Act for certain renewable energy power facilities. The U.S. Department of Agriculture also provides significant financial support through grants, loans, and loan guarantees for development and implementation of renewable energy in the agricultural and forestry sectors and in rural communities. Other federal and state tax incentives as well as state grants and rebates, particularly in states with system benefit charges, also subsidize energy efficiency and renewable energy. As noted, an RPS is also a form of renewable energy subsidy.

Another tool to promote renewable energy is support of *R&D funding*, particularly since technical and economic hurdles remain significant hindrances to deeper renewable energy penetration of the market.

Scholars from Resources for the Future assessed the likely effectiveness and costs of these tools (Fischer and Newell, 2004; Palmer and Burtraw, 2004). Their analyses suggest that the RPS route and other renewable energy subsidies may be most effective for increasing renewable energy but that carbon-focused measures, such as a CO_2 cap-and-trade allowance system or emissions fee, would be more effective at reducing CO_2 emissions. In part this is because RPSs used alone may displace more natural gas than coal for power production. The CO_2-focused measures, in contrast, provide incentives for low carbon fuels (natural gas rather than coal) and energy efficiency as well as renewable energy. Combining these approaches has merit as well as costs. The studies also suggest that a focus on renewable energy R&D is perhaps the most costly and least efficient route among the policy approaches examined to expand renewable energy and reduce greenhouse gas emissions. An R&D emphasis is a technology-push strategy that needs to be matched with market-pull policies and conditions in order to effectively introduce and diffuse new technologies into the marketplace.[17]

Some critics contend that renewable energy is already heavily subsidized and that such measures unnecessarily raise costs, reduce economic welfare, and distort markets. These contentions ignore the implicit subsidy to fossil energy of external costs of human health and environmental impacts. They also do not consider the heavy direct taxpayer subsidies given to fossil and nuclear power.

The Congressional Research Service notes that during fiscal years (FY) 1973 through 2003 federal R&D spending (in year 2003 constant dollars) for nuclear fission and fusion amounted to \$49.7 billion, for fossil energy \$25.4 billion, for renewable energy \$14.6 billion, and for energy efficiency \$11.7 billion. Over the longer period of FY 1948 through FY 2003, 56% (\$74 billion) went to nuclear, 24% (\$30.9 billion) to fossil, 11% (\$14.6 billion) to renewables, and 9% (\$11.7 billion) to energy efficiency (Sissine, 2005).

Non-R&D subsidies to fossil and nuclear energy also abound, including liability limitations for nuclear power plant operators; immediate expensing of coal, oil, and natural gas exploration and development costs; highly generous depletion allowances and "intangible" drilling cost tax deductions; federal subsidy of the

Black Lung Fund; non-conventional fuel production tax credits that have mainly benefited fossil fuel production; eligibility of advanced nuclear reactors for loan guarantees and production tax credits under the Energy Policy Act; and an Energy Policy Act provision to provide $1 billion over four years to states that produce offshore oil and gas, among others.

Renewable energy is available to meet our electricity needs and help solve major environmental problems, including the challenge of global warming. The myth that renewable energy resources are insufficient or too diffuse to meet U.S. electricity demand growth is untrue. In principle, the U.S. renewable energy resource base can meet national electrical demand many times over although significant technical and economic challenges remain.

The path forward requires policies to internalize costs to health and the environment, including alteration of our climate. This will stimulate clean energy markets, investment, and technological advance, leading to more efficient energy use and a cleaner energy supply. Over time renewable energy use will increase and humanity can transition toward sustainably living off of nature's income rather than depleting nature's capital.

NOTES

[1] Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emitted by power plants can undergo changes in the atmosphere to form fine particulates. Power plants also emit particulate matter directly.

[2] DOE data were for 2004 emissions. (EIA, 2006, Table A8, p. 148) EPA data on 2003 emissions were used to derive rough proportion of electrical generating related emissions to total emissions. (EPA, 2005a, nitrogen oxides and sulfur dioxide national emissions totals tables). NO_x consists of several compounds but by convention the mass of emissions is reported as NO_2.

[3] For instance, the EPA Chesapeake Bay Program estimates about 25% of nitrogen load to the Chesapeake Bay is from atmospheric deposition, though this may be from ammonia as well as NO_x emissions. (Chesapeake Bay Program, 2005).

[4] Percentages vary slightly depending if combined heat and power (CHP) plants for off-site energy sale and end-use generation are included. These contribute 5 and 4%, respectively, to total electricity generation.

[5] Percentages vary slightly depending if CHP plants for off-site energy sale (4% of total capacity) and end-use generation (3% of total capacity) are included.

[6] Carbon sequestration is the process of removing CO_2 from the air or a power plant either by physical or chemical separation and geological storage (for instance, in deep aquifers, old oil and gas fields, or deep ocean) or by nurturing biological fixation by plants into plant material and soil organic matter.

[7] Dukes (2003) estimated the amount of ancient biomass required to create fossil fuels. He calculated that one gallon of gasoline required 90 metric tons of precursor biomass. The geological processes of converting biomass in fossil fuels are highly inefficient. Dukes calculated that one year's (1997) human fossil fuel use is derived from organic material equivalent to over 400 times the annual net primary productivity (essentially all photosynthesis minus respiration) of the Earth's current biota. In contrast, using biomass more directly is much more efficient. He estimated that fossil fuels could be replaced by increasing current human exploitation of biomass (from agriculture, forestry, fisheries, and other extraction of plant and animal material) by about 50%.

[8] For instance, quantum dot-based PVs may potentially achieve over 40% efficiency. (Weiss, 2006).

[9] It should be noted that PVs at an electric customer's facility competes against the retail electric rate as compared to the electric utility's wholesale cost. PV-generated electricity used onsite has little or no

transmission and distribution cost, while power entering the electric grid – PV or otherwise – to serve other customers will entail such costs.

[10] The California Solar Inititiative is a 10-year, $2.9 billion program with a goal of 3,000 MW of installed solar electric capacity by 2017 (CPUC, 2006).

[11] Wind resources are divided into seven classes based on mean power density and corresponding wind speeds at a specified height. DOE considers class 4 and above (at least 400 W/m^2 and 7 m/s) to be suitable for current advanced turbines while class 3 (300–400 W/m^2 and 6.4–7 m/s) may be viable in the future (DOE, 2005d). The wind industry is more optimistic about class 3 resource viability.

[12] Capacity or availability factor is the proportion of energy delivered as compared to energy that could be delivered if the facility operated continuously with no stoppages at its stated capacity. For comparison, U.S. nuclear plants operated at close to 90% capacity factor during 2002–2004 and coal units may be in the 75% range. (DOE, 2006a; IAEA, 2006).

[13] MSW may also include combustible non-biomass/non-renewable energy components, such as plastics.

[14] The DOE assessment covers only 49 states; data from Delaware were unavailable.

[15] The phase down of leaded gasoline in the United States and wetland banking to compensate for wetland development are non-emissions examples of this approach. Certain fishing allowances and New York City taxicab medallions are still other cap-and-trade examples.

[16] Pennsylvania has an alternative energy portfolio standard that includes, in addition to renewable energy, certain non-renewable energy technologies such as advanced cleaner coal, coal waste utilization, and CHP technologies.

[17] See discussion of technology-push, market-pull, and models of innovation discussion in OTA (1995).

REFERENCES

Abt Associates, Inc.: 2004, “Power Plant Emissions: Particulate Matter-Related Health Damages and the Benefits of Alternative Emission Reduction Scenarios,” prepared for the Clean Air Task Force, [online] http://www.cleartheair.org/dirtypower/docs/abt_powerplant_whitepaper.pdf, accessed March 7, 2006.

Aitken, D.: 2005, “Germany Launches Its Transition to All Renewables,” March 10, 2005, *Solar Today*, reproduced by SustainableBusiness.com, [online] accessed http://www.sustainablebusiness.com/features/feature_printable.cfm?ID=1208, March 7, 2006.

American Bird Conservancy: 2004, “American Bird Conservancy Wind Energy Policy,” [online] http://www.abcbirds.org/policy/windpolicy.htm, accessed March 7, 2006.

[AWEA] American Wind Energy Association: 2006a, “Wind Energy and Wildlife: Frequently Asked Questions,” [online] http://www.awea.org/pubs/factsheets/050629_Wind_Wildlife_FAQ.pdf, accessed March 7, 2006.

[AWEA] American Wind Energy Association: 2006b, “Wind Energy Basics,” [online] http://www.awea.org/faq/tutorial/wwt_basics.html, accessed March 7, 2006.

[AWEA] American Wind Energy Association: 2006c, “Wind Energy Potential,” [online] http://www.awea.org/faq/tutorial/wwt_potential.html, accessed March 7, 2006.

Appenzeller, T.: 2006, “The Coal Paradox,” *National Geographic* **209**:3 (March 2006), pp. 98–103.

Bat Conservation International: 2006, “Bats & Wind Energy” [online] http://www.batcon.org/home/index.asp?idPage=55&idSubPage=26, accessed March 7, 2006.

Brown, Marilyn A., Levine, Mark D., Short, Walter, and Koomey, Jonathan G.: 2001, “Scenarios for a Clean Energy Future,” *Energy Policy* **29**:14, pp. 1179–1196.

Burtraw, D. and Palmer, P.: 2003, “The Paparazzi Take a Look at a Living Legend: The SO_2 Cap-and-Trade Program for Power Plants in the United States,” Resources for the Future, Discussion Paper 03-15, April 2003, [online] http://www.rff.org/Documents/RFF-DP-03-15.pdf, accessed March 7, 2006.

California Public Utility Commission (CPUC): 2006, "PUC Creates Groundbreaking Solar Energy Program," [online] http://www.cpuc.ca.gov/PUBLISHED/NEWS_RELEASE/52745.htm, accessed June 4, 2006.

[CEED]Center for Energy and Economic Development: 2006, Fuel Resources Table, [online] http://www.ceednet.org/ceed/index.cfm?cid=7538,7595,7816, accessed June 4, 2006.

Chesapeake Bay Program: 2005, "Air Pollution," [online] http://www.chesapeakebay.net/air_pollution.htm, accessed June 7, 2006.

[DSIRE] Database of State Incentives Rules, Regulations, & Policies for Renewable Energy (DSIRE): 2006, [online] http://www.dsireusa.org/summarytables/reg1.cfm?& CurrentPageID=7 &EE=0&RE=1, accessed March 7, 2006.

Dukes, J.S.: 2003, "Burning Buried Sunshine: Human Consumption of Ancient Solar Energy," *Climatic Change* **61**, pp. 31–44.

[EIA] Energy Information Administration, U.S. Department of Energy: 2005a, *Annual Coal Report*, Coal Production and Coalbed Thickness by Major Coalbeds and Mine Type, [online] http://www.eia.doe.gov/cneaf/coal/page/acr/table5.html, accessed March 7, 2006.

[EIA] Energy Information Administration, U.S. Department of Energy: 2005b, *International Energy Outlook 2005*, DOE/EIA-0484 (2005), [online] http://www.eia.doe.gov/oiaf/ieo/electricity.html, accessed June 4, 2006.

[EIA] Energy Information Administration, U.S. Department of Energy: 2005c, "Regional Energy Profile: U.S. Household Electricity Report," [online] accessed http://www.eia.doe.gov/emeu/reps/enduse/er01_us.html, June 4, 2006.

[EIA] Energy Information Administration, U.S. Department of Energy: 2005d, *Annual Energy Outlook 2005*, DOE/EIA-0383 (2005), Washington, DC [online] http://www.eia.doe.gov/oiaf/archive.html, accessed June 22, 2006.

[EIA] Energy Information Administration, U.S. Department of Energy: 2006, *Annual Energy Outlook 2006*, DOE/EIA-0383 (2006), [online] http://www.eia.doe.gov/oiaf/aeo/index.html, accessed March 7, 2006.

EnviroTruth.org: "Myth #9: Associated Energy Myth: Solar and Wind Power Can Soon Be Significant Contributors to the Base Load Energy Needs of Canada and the United States," [online] http://www.envirotruth.org/myth9.cfm, accessed June 4, 2006.

[EWEA] European Wind Energy Association: 2005, "Large Scale Integration of Wind Energy in the European Power Supply: Analysis, Issues, and Recommendations," http://www.ewea.org/index.php?id=178, accessed March 7, 2006.

Fischer, C. and Newell, R.: 2004, "Environmental and Technology Policies for Climate Change and Renewable Energy," Resources for the Future Discussion Paper 04-05, Resources for the Future, Washington, DC, USA.

Huq, Z.: "Biomass for Electricity Generation," DOE, Energy Information Administration, [online] http://www.eia.doe.gov/oiaf/analysispaper/biomass, accessed March 7, 2006.

Interlaboratory Working Group: 2000, *Scenarios for a Clean Energy Future*, Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory, ORNL/CON-476 and LBNL-44029, [online] http://www.ornl.gov/sci/eere/cef/, accessed March 7, 2006.

[IAEA] International Atomic Energy Agency: 2006, "Nuclear Power Plants Information: Last Three Years Energy Availability Factor," [online] http://www.iaea.org/cgi-bin/db.page.pl/pris.factors3y.htm?faccve=EAF&facname=Energy%20Availability%20Factor&group=Country, accessed March 7, 2006.

Kutscher, C.: 2000, "The Status and Future of Geothermal Electric Power, 2000," presented at the *American Solar Energy Society Conference*, Madison, WI, June 16–21, 2000, NREL/CP-550-28204, [online] http://www.nrel.gov/docs/fy00osti/28204.pdf, accessed March 7, 2006.

Lemieux, P.M.: 1998, *Project Summary: Evaluation of Emissions from the Open Burning of Household Waste in Barrels*, EPA, National Risk Management Research Laboratory, EPA/600/SR-97/138, [online] www.epa.gov/ttn/atw/burn/trashburn1.pdf, accessed March 7, 2006.

Milloy, S.: 2004, "Renewable Energy, Enviros and New Job Creation," (18 April, 2004) on FoxNews.com, [online] http://www.foxnews.com/printer_friendly_story/0,3566,117223,00.html, accessed June 4, 2006.

Mitchell, J.G.: 2006, “When Mountains Move,” *National Geographic* **209**:3 (March 2006), pp. 104–123.

[NCEP] National Commission on Energy Policy: 2004, “Ending the Energy Stalemate: A Bipartisan Strategy to Meet America’s Energy Challenges,” p. 62, [online] http:// www.energycommission.org/materials/, accessed March 6, 2006.

[NREL] National Renewable Energy Laboratory, Energy Analysis Office, U.S. Department of Energy: 2002, “Renewable Energy Cost Trends,” [online] http:// www.nrel.gov/analysis/docs/cost_curves_2002.ppt, accessed March 6, 2006.

[NREL] National Renewable Energy Laboratory, U.S. Department of Energy: 2004, *PV FAQ: How much land will PV need to supply our electricity?* DOE/GO-102004-1835, [online] http://www.nrel.gov/ncpv/pdfs/land_faq.pdf, accessed March 7, 2006.

[NWCC] National Wind Coordinating Committee: 2004, “Wind Turbine Interactions with Birds and Bats: A Summary of Research Results and Remaining Questions,” [online] http://www.nationalwind.org/publications/wildlife/wildlife_factsheet.pdf, accessed March 7, 2006.

[ORNL] Oak Ridge National Laboratory: 2006, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, DOE/GO-102995-2135 and ORNL/TM-2005/66, [online] http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf, accessed June 4, 2006.

[OTA] Office of Technology Assessment, U.S. Congress: 1995, *Innovation and Commercialization of Emerging Technologies*, OTA-BP-ITC-165, U.S. Government Printing Office, Washington, DC, USA.

Palmer, P. and Burtraw, D.: 2004, “Electricity, Renewables, and Climate Change: Searching for a Cost-Effective Policy,” Resources for the Future, Washington, DC, USA.

Raymond, Lee: 1997, Speech at the World Petroleum Congress, Beijing, October 13, 1997.

Reece, E.: 2006, “Moving Mountains: The Battle for Justice Comes to the Coal Fields of Appalachia,” *Orion*, January/February 2006, [online] http://www.oriononline.org/pages/om/06-1om/Reece.html, accessed March 7, 2006.

[RGGI] Regional Greenhouse Gas Initiative: 2006, [online] http://www.rggi.org/, accessed March 7, 2006.

Sissine, F.: 2005, *Renewable Energy: Tax Credit, Budget, and Electricity Production Issues*, Library of Congress, Congressional Research Service, Order Code IB 10041, Washington, DC, USA.

[SEIA] Solar Energy Industries Association: Solar Energy Types 2006, [online] http://www.seia.org/solartypes.php#, accessed March 6, 2006.

Solarbuzz: Portal to the World of Solar Energy 2006a, [online] http://www.solarbuzz.com/index.asp, accessed March 7, 2006.

Solarbuzz: 2006b, Price survey for February 2006, [online] http://www.solarbuzz.com/SolarPrices.htm, accessed March 6, 2006.

[UCS] Union of Concerned Scientists: 2005, “Increasing Renewables: Costs and Benefits,” [online] http://www.ucsusa.org/clean_energy/renewable_energy_basics/increasing-renewables-costs-and-benefits.html, accessed March 6, 2006.

[DOE] U.S. Department of Energy: 2004, *Windpowering America: Clean Energy for the 21st Century*, DOE/GO-102004-1899, [online] http://www.nrel.gov/docs/fy04osti/35873.pdf, accessed March 7, 2006.

[DOE] U.S. Department of Energy: 2005a, “Hydropower Resource Potential,” [online] http://www1.eere.energy.gov/windandhydro/hydro_potential.html, accessed March 7, 2006.

[DOE] U.S. Department of Energy: 2005b, “Ocean Tidal Power,” [online] http://www.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50008, accessed March 7, 2006.

[DOE] U.S. Department of Energy: 2005c, “Ocean Wave Power,” [online] http://www.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50009, accessed March 7, 2006.

[DOE] U.S. Department of Energy: 2005d, “Wind Energy Resource Potential” [online] http://www1.eere.energy.gov/windandhydro/wind_potential.html, accessed March 7, 2006.

[DOE] U.S. Department of Energy: 2006a, “Geothermal FAQs,” [online] http://www1.eere.energy.gov/geothermal/faqs.html, accessed March 7, 2006.

[DOE] U.S. Department of Energy: 2006b, “Ocean Thermal Energy Conversion,” [online] http://www.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50010, accessed March 7, 2006.

[EPA] U.S. Environmental Protection Agency (EPA): 2005a, *Air Trends*, [online] http://www.epa.gov/airtrends/2005/econ-emissions.html, accessed March 7, 2006.

[EPA] U.S. Environmental Protection Agency: 2005b, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*, EPA 430-R-05-003, [online] http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR69V528/$File/05executivesummary.pdf, accessed March 7, 2006.

[EPA] U.S. Environmental Protection Agency (EPA): “Landfill Methane Outreach Program” overview web page, [online] http://www.epa.gov/lmop/overview.htm, accessed March 7, 2006.

[USFWS] U.S. Fish and Wildlife Service (USFWS): 2002, “Migratory Bird Mortality: Many Human-Caused Threats Afflict Our Bird Population,” [online] http://birds.fws.gov/mortality-fact-sheet.pdf, accessed March 7, 2006.

Verdant Power [online] http://www.verdantpower.com/initiatives/currentinit.html, accessed March 7, 2006.

Weinberg, C.J. and Williams, R.H.: 1990, “Energy from the Sun,” *Scientific American* (September 1990), pp. 147–155.

Weiss, P.: 2006, “Quantum-Dot Leap,” *Science News* **169**:22, pp. 344–345.

White, D.: 2004, “Reduction in Carbon Dioxide Emissions: Estimating Potential Contribution From Wind-Power,” Renewable Energy Foundation, [online] http://www.countryguardian.net/whiteco2.pdf, accessed June 4, 2006.

CHAPTER 9

ENERGY MYTH EIGHT – WORLDWIDE POWER SYSTEMS ARE ECONOMICALLY AND ENVIRONMENTALLY OPTIMAL

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Debates on energy policy, environmental regulation, and global warming start with the largely unquestioned assumption that the present heat and power system is economically optimal. It then follows that any actions to change the energy system to achieve other goals, such as lowering pollution, will raise the cost of energy services and damage the economy. It then further follows that the only way to have affordable, clean energy is to invent and develop new technology. This view is widespread. President George W. Bush, in a major speech on climate change said, "Technology is the ticket" (2005).[1] But the energy system is not optimal, and society does not need to play off income against cleaner energy.

We question this near-universal belief that new technology is the most important requirement to mitigate climate change. Although the energy system is the world's largest single industry, energy entrepreneurs are not free to innovate in the manner of other industries. Our conventional wisdom that markets are efficient has to take into account that there is no truly functioning market in the electric sector, at least not to the degree we would like to believe. In fact, it is virtually the only remaining mega industry that is centrally planned (by Public Utility Commissions) and works on 5-year plans (called rate cases).

These regulations and monopoly protections create significant barriers to energy system innovation and largely prevent the deployment of proven technologies that could reduce net energy costs *and* reduce emissions. Eliminating barriers to energy innovation is job one of anyone concerned with energy costs, fossil emissions, national security implications of fossil fuel use, or retention of manufacturing jobs.

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Few assumptions that underpin government policies are as flawed as the myth that the electric power system is optimal and that industrial energy use is optimal. The power industry has made suboptimal choices for at least 30 years, resulting in needless capital expenditures, excessive fossil fuel use, unnecessary pollution, and overpriced power. Nor have manufacturing industries optimized their energy production. Industrial enterprises typically treat energy as a non-core activity and then severely ration intellectual and financial resources devoted to energy efficiency projects. Industry regularly ignores energy saving projects with one to two year paybacks. The resulting opportunities should be fertile ground for third party power entrepreneurs seeking to profit by outsourcing industrial energy supply. But regulations and regulators, bent on protecting electric distribution monopolies, largely compromise the economics of such projects. The failure to optimize U.S. power systems is principally caused by power industry governance, which consists of a vast tapestry of rules and regulations that either was based on yesterday's technology choices or was handcrafted by electricity distribution utilities to preserve their wires monopoly.

It is instructive to quantify the magnitude of U.S. power system sub-optimality. It will take the whole chapter to explain these conclusions fully:

- The U.S. economy could profitably drive 64,000 MW of new generation by recycling present industrial waste energy streams. Assuming this new energy recycling capacity operated 70% of the year, it would generate 392 billion kWh per year and avoid four quadrillion Btu's (quads) of fossil fuel per year.
- The U.S. could, by generating electricity locally near thermal users, profitably recycle one-half of the presently wasted heat from power generation and save 13 quads of fossil fuel.
- The 17 quads of avoided fossil fuel would reduce energy costs by $70 billion per year and cut U.S. fossil fuel use from 85.7 quads total use in 2004 (EIA, 2005) to 68.7 quads, roughly a 20% drop in fossil fuel and in associated CO_2 greenhouse gas emissions.
- Profitably recycling this waste energy would produce many other positive benefits. The savings would preserve manufacturing jobs. All air pollution would drop by the same amount or more. The resulting reduction of fossil fuel use would help moderate world fuel prices. There would be a sustained boom in new power plant construction. System vulnerability to terrorists and extreme weather conditions would drop, due to the widely dispersed generation near users. (Waste energy can only be recycled by power plants near the users.) Finally, the rest of the world would be forced to recycle its waste energy to remain competitive.

We believe that the inefficiency of the American energy industry represents an unfolding disaster that exacerbates many current problems, including manufacturing competitiveness, jobs, national security, electric transmission system vulnerability to extreme weather conditions and terrorism, balance of payments, and global warming. We will show how regulatory/governance changes could positively address each of these problems by simply removing the barriers to efficiency and by encouraging the re-use – or as we term it, recycling – of presently wasted energy streams in both industrial production and electric power generation.

How does the myth of an optimal power system survive? Electric power is the country's largest industry, comprised of many very large, very profitable firms that invest heavily in public relations. Indeed, the National Academy of Engineering (2006) recently called the current electric utility system "the greatest engineering achievement of the 20th century," ranking it above inventions such as the automobile, television, airplane, and radio. A recent survey of state regulators undertaken by the Edison Electric Institute (Hirst, 2004, p. 1) found that almost one-fourth of state regulators in the west, one-half in the east, and two-thirds in the south described the American electric utility system as "fully adequate." Similarly, a report from the North American Electric Reliability Council (2005, pp. 5–6) concluded with a "favorable outlook" of the industry and predicted that electrical resources will be more than adequate to meet customer demand until at least 2009.

Moreover, the electric utility industry insists that they are totally committed to customer goals, which reinforces the myth that they are optimally producing and delivering electricity. Entergy's 2005 Annual Report to Shareholders states (p. 12), "Our mission is to safely provide our customers with clean, affordable, and reliable power." Con Edison's 2005 Annual Report says, "Con Edison is committed, 24 hours a day, seven days a week, to providing the safe and reliable delivery of energy while preparing for our region's energy future."

Furthermore, standard economic theory says that competition forces firms to continually improve and wring waste out of every process. Competitive markets, according to the theory, do not leave $100 bills lying on the ground; some entrepreneur will have already picked them up. Since headlines claim that the electric industry has been "deregulated," the public assumes that market forces – Adam Smith's "invisible hand" – will have reduced power industry waste and driven down the cost of delivered electricity. For example, a recent article in *Public Utilities Fortnightly* argued that "market solutions" would inevitably "compete to build" whatever new investments were needed in the industry (Huntoon and Metzner, 2003). And, when assessing the success of electric utility restructuring throughout the late 1990s, Timothy J. Brennan et al., (2002, p. 1) emphasize "opening markets to competition generally gives firms better incentives to control costs and introduce innovations."

But the idea that deregulation has introduced effective true competition, especially to local generation where technology has the most to offer, fails the laugh test. Century-old grants of monopoly rights to distribute electricity remain in place and are enforced in every territory to discourage local or on-site generation. It is time for a reality check. If deregulation has allowed true competition, markets should be working. Is the electric system becoming more efficient? Has deregulation removed key barriers to efficiency?

Sadly, the broad answer is no. A century of monopoly protection has spawned many anticompetitive rules. For electric distribution, these anticompetitive rules remain in force. The single most damaging barrier to competition is the universal ban on private electric wires crossing public streets. These bans force would-be power entrepreneurs to use their competitors' wires to deliver their product – electricity, to their customers. Utilities and regulators then set prices for moving power that deeply penalize local generation. A second major barrier to competition is the unique reward system that applies to monopoly-protected activities such as electric power. Regulators approve rates that are supposed to provide a "reasonable" return on invested capital. This encourages capital investment, regardless of efficiency. By contrast, competitive markets reward low-cost production. Electric power utilities present a test case scenario of assumed electric sales and then negotiate rates with their regulatory commissions for each class of customer. The market plays no role. With approved rates in place, the utility's profits hinge on throughput – how much electricity flows through their wires. More sales, more profits. Actions that lead to conservation, appliance efficiency gains, and local generation all penalize utility profits. Generation efficiency gains do not help profits, as they are passed through to customers. Society gets what these rules pay for – stagnant efficiency and endless barriers to more efficient local generation.

The record confirms this. The U.S. power system used three units of fuel to deliver one unit of electricity in 1959. Although the ensuing 46 years have seen phenomenal technology advances, which makes energy "recycling" cost-effective, the power industry's dismal 33% efficiency level has not changed (EIA, 2005). We need look no further for proof of regulatory failure than the power industries failure to recycle waste energy streams to cut consumer costs and fossil emissions.

Deregulation has opened some parts of the industry to competition, which has worked, but only in the ways the rules reward. The Energy Policy Act of 1992 opened wholesale electric generation competition, i.e., for power sold to the grid, and this induced electric power companies to improve labor and capital utilization efficiencies. The U.S. power industry employed 75 persons per 100 MW of generating capacity in 1990. By 2004 the utility industry reduced that number by 52% to 39 persons per 100 MW of generating capacity. The load factor for all nuclear units rose from 66% in 1990 to 88% in 2003, while coal fired load factors rose from 59 to 72%. During the same period, the industry only increased its coal and nuclear electric generating capacity by 5 GW, or a 1% increase (407 GW in 1990). But the power output from these coal and nuclear plants increased by 26% (EIA, 2005). This improvement avoided the construction of 100 GW of new generating capacity. The industry would have otherwise needed to build new coal and nuclear plants, which would have added roughly $150 billion to the U.S. rate base, raising rates by $18 billion per year. But the partial market opening, by allowing only wholesale competition failed to cause improvements in fuel efficiency.

Some pundits ignore these facts, and claim that since electricity prices have risen, deregulation has failed. But to believe that the price of delivered power provides insight into the impact of deregulation assumes that all other things were equal. In fact, world fuel prices have risen dramatically, tripling and even quadrupling the cost of fuel for electric power generation since 2000. These fuel price increases, with no efficiency gains, have overwhelmed the gains that limited deregulation promoted in central plant labor and capital productivity and caused electric rates to rise to consumers. To put the past in Adam Smith terms, the regulations prior to

1978 shackled both “invisible hands” of would-be competitors. The Public Utility Regulatory Policies Act in 1978 and the 1992 Energy Policy Act largely untied one hand, allowing third parties, under limited circumstances, to generate power and compete with other centralized generation plants. But the regulatory barriers to any local generation that bypasses the distribution grid have remained in place, keeping one “invisible hand” shackled.

But for this limited opening of competition, today’s electric prices would be even higher, but the failure to reward efficiency has created problems. The steady growth of electric use without any improvement in efficiency has dramatically increased the demand for fossil fuel, and has helped drive spot coal prices to levels four times higher than they were 15 years ago. The power industry’s adoption of natural gas fired plants has increased gas demand and strongly contributed to the dramatic rise in natural gas prices, all of which flows through to consumer prices.

This chapter explains how the electric power industry, if faced with truly free competition, would reduce fuel use for electric power and would recycle industrial energy waste streams. Opening of competition will create a virtuous cycle of efficiency gains, lessening the demand for fuel, which will then moderate fuel price increases.

9.1. PART I: UNDERSTANDING OPTIMAL GENERATION

9.1.1 Recycling Energy – A Casualty of Governance

To understand what is wrong with today’s power system, three points are sufficient. First, realize that manufacturing processes *and* electric power generation plants only convert a portion of available energy in the fuel that is burned into useful work. The remaining potential energy is typically discarded. As just noted, the U.S. electric power generation system, on average, discards two thirds of its input energy as waste. Many industrial processes also discard prodigious quantities of potential energy. Second, understand that much of the waste energy from manufacturing and power generation can be profitably recycled into useful heat and power, but only if the energy recycling facility is located at or near users. Thermal energy, the form of much of present waste, does not travel far without losing its value. Third, understand that the U.S. electric power industry remains totally focused on remote central generation plants, none of which can recycle waste heat. This central generation paradigm applies to regulators, the utilities they regulate, and – of necessity – to independent power producers. As a result of this central generation fixation, the power industry burns roughly twice as much fossil fuel as would an economically optimal system using available technology.

There are many proven approaches that could profitably recycle the presently wasted 17 quadrillion Btu’s of energy.[2] This would save money, reduce pollution, mitigate climate change, improve the competitive position of U.S. industry, and create highly skilled jobs. But because recycling energy requires local power generation, it remains out of favor. *The potential to recycle energy may be society’s best kept secret.*

The pervasive myth of an optimal power system helps to keep energy recycling a secret. Surely, it will be argued, the utilities would recycle energy if this saved money. Surely industry would convert waste energy streams into power, if it were economic to do so. Neither assumption matches observed facts.

In order to extract useful work from waste energy, electricity must be generated locally, near users. But utilities do not like local generation because it reduces the electric power flowing through their wires, which under the present system of governance would reduce centralized utility profits. Yet the regulators have not corrected this bias. Utility governance, an unholy alliance of management and regulation, remains locked into a central generation paradigm that made technical and economic sense a century ago, but no longer makes sense. Today, the regulatory system usually supports the central utility's continuing efforts to block generation by local power generators and by waste industrial energy recyclers.

9.1.1.1 Recycling industrial waste energy

It is a well-established fact that a variety of industrial waste energy streams can be recycled into useful heat and electric power. These include hot exhaust gases, low-grade fuels (some of which are typically flared), and high-pressure steam and gas. For example, it is feasible to use hot exhaust (600 °F or higher) from any process to produce steam that drives turbine generators and produces electricity. Hot exhaust is emitted by coke ovens, glass furnaces, silicon production, refineries, natural gas pipeline compressors, petrochemical processes, and many processes in the metals industry.[3] Another way energy can be recycled is by burning presently flared gas from blast furnaces, refineries, or chemical processes to produce steam and electricity.

Pressurized gases also contain energy that can be recycled into electricity. Examples include steam, process exhaust, and compressed natural gas in pipelines. All gas pressure drops can be used to generate electricity via backpressure turbines. Remember the whirly gig, a stick with a plastic propeller? As children, we ran with the stick above our heads, and the motion through the air caused the propeller to turn. Wind turbines adopt the same idea on a much larger scale. But what about "industrial wind" whirly gigs? Industry produces many streams of gas at high pressure that can power an "industrial strength" whirly gig called a backpressure turbine. The turbine drives an electric generator to produce fuel-free power with no incremental pollution.

Nearly every college and university campus, as well as most industrial complexes, could produce some fuel-free electricity from steam pressure drop with a backpressure turbine generator (Turbosteam, online). Gas transmission pipelines burn 8% of the gas being transported to drive compressors that pack the remaining natural gas into transcontinental pipes. Pipelines then reduce that pressure at each city gate with valves, typically wasting the potential energy of the pressure drop. Simply recycling this pressure drop at every point that gas flows into local distribution systems would generate 6,500 MW, roughly 1% of U.S. electric power generation (Primary Energy, online). Industrial processes such as catalytic crackers at petroleum refineries and blast furnaces at steel mills emit exhaust at above atmospheric pressure. A top-gas recovery turbine on a large blast furnace can produce 15 MW of fuel-free power, while a similar device atop a catalytic cracking unit in an oil refinery can produce 35 MW of fuel-free electric power. There are many blast furnaces and many catalytic cracking units in operation 24/7, nearly all wasting potential energy.

Recycling industrial energy streams is well established, but only in facilities large enough to make use of the heat or power internally. There are roughly 10,000 MW of installed industrial recycled energy capacity in operation in the United States, the equivalent of ten large nuclear plants. But this is only 10% of the existing potential to recycle industrial waste energy. A recent study for the U.S. Environmental Protection Agency documented another 95,000 MW of potential recycled industrial energy generation (Bailey and Worrell, 2004). The total savings potential remains significant, even after we trim the estimate to 64,000 MW, based on our development experience. Recycling this waste energy could produce an astonishing 14% of U.S. electricity without burning any fossil fuel. In 2004, 77% of U.S. electricity was produced by burning fossil fuels; recycling industrial energy streams with local generation could avoid burning nearly one fourth of that fossil fuel and save money.

Data on existing industrial energy recycling projects gives a flavor of the range of capacity and capital costs. Energy recycling projects range in capacity from 40 kW to 160 MW (160,000 kW), and capital costs have ranged from $300 per kW for large backpressure turbines to over $1,800 per kW for small steam-turbine plants. For comparison, capital costs per kW of electrical generating capacity for a new coal-fired plant are roughly equal to the most expensive energy recycling plants. But a new coal plant requires fuel and transmission wires while the energy recycling plant converts free waste energy streams into heat and electric power and delivers the power directly to on-site users, avoiding transmission wires.

Figure 9.1 is a picture of Cokenergy, an energy recycling plant located on Lake Michigan, opposite Chicago. Some 268 ovens bake metallurgical coal to produce blast furnace coke – expanded lumps of nearly pure carbon. The Primary Energy plant in the picture recycles waste energy in the hot coke-oven exhaust gas to produce up to 95 MW of electricity and up to 980,000 pounds of steam for Mittal Steel's adjacent Harbor Works steel plant (Primary Energy, online). This plant burns no incremental fossil fuel and emits no incremental air pollution or greenhouse gases. In other words, this power is pristine, as clean as the power from renewable energy sources such as solar collectors. The plant's clean power production is staggeringly large. **In 2004, this plant generated roughly the same amount of clean energy that was produced by all of the grid-connected solar collectors throughout the world.**[4] And it earned a profit selling that power for less than half of the cost of power from the local utility.

Each dollar of investment in this energy recycling plant produced roughly 75 times more clean energy than a dollar invested in solar collectors, or ten times more clean energy than a dollar invested in wind generation and wires.[5] These comparisons are not intended to disparage the use of renewable energy, but to

Figure 9.1. Cokenergy – energy recycling plant at Mittal Steel, East Chicago, Indiana

demonstrate the economic efficiency of recycling energy. Recycled energy is clean, affordable, and a profitable way to reduce CO_2 emissions.

Mittal Steel enjoys significant economic benefits without capital investment. Mittal saved roughly $40 million in 2005 versus producing the same steam with natural gas and purchasing electricity from the grid. Energy recycling thus makes industry more competitive and preserves jobs, while reducing costs, pollution, and dependence on imported fuel.

This project is the exception that proves the rule of suboptimal electric power generation. A sister coke plant in Van Zant, Virginia, has operated for 35 years without recycling the potential energy in its exhaust. Other examples illustrate current waste. The world produces roughly 3 million pounds of nearly pure silicon in smelters that exhaust hot gas similar to Cokenergy. To the best of our knowledge, none of the hot gases is recycled, even though they could produce 6.5 billion kWh per year, nearly 10 times the current production of clean power from worldwide solar energy. There are countless examples of other sources of hot exhaust that are currently wasted, but could be profitably recycled into heat and electric power with existing technology if barriers to efficiency were removed. **It is simply a myth that the power system is optimal**.

9.1.1.2 Recycling waste heat from electric generation

So far, we have focused on recycling waste energy streams from industrial facilities. We have shown that recycling industrial waste heat has the potential to produce 14%

of U.S. electric power with no incremental fossil fuel or pollution. Now we turn to an even larger potential, recycling the copious quantities of waste heat from thermally based electric generation plants (plants using fossil fuels, biomass, or nuclear energy to produce electricity). To recycle energy from electric power generation, one must extract waste heat at slightly higher temperatures, which slightly reduces electric output. This thermal energy, extracted at small cost to the electricity produced, can then supply space heating, water heating, absorption cooling, and some industrial processes, displacing boiler fuel. But to recycle its waste heat, an electric generation plant must be located at or near thermal users and sized to their thermal needs. Low temperature heat cannot be economically transported over long distances. Electric generation heat recycling requires many smaller, on-site plants instead of today's system of large, remote generating stations.

We can roughly estimate the potential savings from constructing new combined heat and power generation units near thermal users. In 2003, the U.S. power industry consumed 28.2 quads of fossil fuel to deliver 9.2 quads of electricity. This corresponds to the 33% efficiency already cited (EIA, 2005). By contrast, combined heat and power plants (CHP) sited near thermal users are able to achieve anywhere from 50 to 90% efficiency, depending on configuration and local demand for thermal energy. Recycling half of the heat currently thrown away by fossil-fueled central generation plants would supply an additional 9.4 quads of useful energy for heating and process use. This would avoid burning 13.4 quads of boiler fuel that is currently used to supply the same thermal energy. **This would save half of all fossil fuel used for electric generation today, or over 15% of all fossil fuel burned in the United States**. This energy recycling potential is in addition to the savings of four quads of fossil fuel from recycling industrial waste energy into electric power that were noted above.

These approaches make sense all over the world. The global potential for reducing fuel use with local (decentralized) CHP could significantly reduce worldwide demand for fossil fuels. Today, 92.5% of the world's electricity is produced at remote, inherently wasteful central generation plants (WADE, online). The world can use existing proven technology to drive the percentage of power from local CHP plants to over 50% of total use. Denmark has already achieved this goal. Surprisingly, no new technology is needed to achieve these savings; CHP plants utilize all of the technologies and fuels used by central generation plants, including nuclear power.[6] Inducing the power industry to recycle energy would also stimulate technical improvements, which would further increase the potential to recycle power plant waste energy profitably. Finally, although typical local CHP generation facilities will be smaller than centralized remote generation plants, they are still substantial plants, ranging from a few kW to 700 MW.

The *World Survey of Decentralized Energy for 2005* by the World Alliance for Decentralized Energy (WADE) (WADE, online) found that 7.5% of worldwide electric generation was from CHP plants but noted a great disparity among countries, as shown in the chart. The United States and Canada generated respectively 7.2 and 9.9% of their power with CHP plants, while some other industrial economies

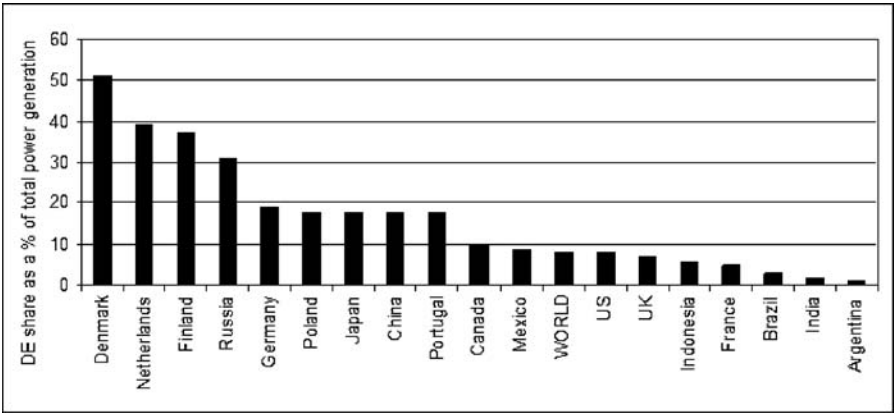

Figure 9.2. CHP production percentage of total power by country (derived from WADE, online)

generated between 30 and 52% of their power with more efficient CHP plants (See Figure 9.2). (The statistics do not show how much thermal energy was recycled, but only whether the power was generated by a plant capable of recycling waste thermal energy.)

It is also interesting to note the difference in use of CHP plants among U.S. states. Three states report that they have no combined heat and power production, while California and Hawaii produced over 20% of their power with CHP plants. These differences in the use of CHP among countries and among U.S. states have little to do with the local mix of energy users. The differences are largely explained by local power industry governance. In those countries and U.S. states that have removed some of the barriers to efficiency and begun to credit local generation with more of the value it creates, the power industry has built nearly all new generation facilities next to thermal energy users. The three states with no reported CHP plants retain old laws that make it illegal for a third party to sell power to a host, even if the generation plant is on the host property.[7] Such governance blocks innovation.

9.1.2 Do Central Plants have Economies of Scale?

Some power industry specialists acknowledge the efficiency advantages of local CHP generation, but claim offsetting economies of scale for centralized generation. Indeed, there are economies of scale, if one looks only at the capital cost of the generation plant. According to the International Energy Agency's *World Energy Outlook 2002* (IEA, 2002) the expected average cost of all new central generation in 2002 dollars was $890 per kW of capacity, which was 25% less than our estimated average cost of new decentralized plants.[8] But this is the answer to the wrong question. This number ignores the added capital costs for transmission, distribution, and redundancy.

Transmission wires in the United States, and indeed in the world, are in short supply. Numerous recent power interruptions have flagged problems with overloaded transmission systems in the United States and Europe. Many developing countries, such as India, experience daily blackouts as transmission capacity has to be rationed among customers. To serve electric load growth with new central generation plants, it is necessary to construct new transmission and distribution systems (T&D). A kilowatt of new T&D capacity has been estimated to cost, on average, $1,380 per kW of capacity (Arthur and Little, 2000). New T&D costs more than new central generation per kW of added capacity.

Others have confirmed the magnitude of T&D costs. The Regulatory Assistance Project (RAP) did a detailed study of public information from 124 U.S. utilities over 1995–1999 and found the average annual investment in distribution wires by each company was $6.4 million per year, or nearly $50 billion per year in total. This will require electric rate increases of roughly $6 billion per year. RAP writes, "While generating costs may experience a decline through technological gains in efficiency, costs of the distribution system have no comparable innovations in the wings" (Shirley, 2001).

By contrast, new on-site generation avoids the T&D system by delivering power directly to local customers. A small investment in the distribution system may be required to interconnect local generation to the grid. But the added cost will seldom exceed 10% of the cost for new T&D from a new remote central generation facility.

It should be noted that utility requests for standby rates typically claim much higher costs to provide interconnection and backup power to a local CHP generator. These calculations are designed to discourage local generation that would lower utility throughput. They often assume that the on-site generation plant will fail at the precise moment of peak system load. Using this logic, the utilities often claim they must dedicate grid and generation capacity to supply 100% of the user's peak load. Such analysis is deeply flawed. CHP plants often consist of multiple generators, which experience random failure rates of about 2% per year. The probability of all three generators in a typical CHP plant failing simultaneously and at the exact time of the system peak load is about one in 6.25 million.[9] Furthermore, once a reformed regulatory system encourages local power generation, any single local plant failure is likely to be lost in the noise, offset by the ability of other CHP units to increase their output. Nevertheless, electric power industry regulators have nearly always approved excessive standby charges. Such charges effectively block economically and environmentally optimal energy use. Local CHP generation avoids new T&D, reduces existing line losses, cuts air pollution, and enhances grid reliability (Alderfer et al., 2000). Instead of requiring local generation to pay standby fees to the utility, regulations should require payment to local generators for the net savings to the grid that these plants create.

With this information, we can fully address the question of economies of scale by calculating the overall costs of central versus on-site or local power. Table 9.1 makes this calculation. The third column shows that one kilowatt of new central capacity and necessary T&D will require 170% more capital investment than building the

Table 9.1. Capital to Serve an Incremental Kilowatt of Peak Load (based on IEA, 2002)

	Generation	Transmission & distribution	Total kW of new generation	KW of kW load	Costs/kW of new load
Central generation	$890	$1,380	$2,270	1.44	$3,269
Local generation	$1,200	$138	$1,338	1.07	$1,432
Savings (excess) of central versus local generation	$310	($1,242)	($1,068)	−0.37	($1,837)
Central generation capital as a percent of local generation capital	74%	1000%	170%	135%	228%

same kilowatt of local generation capacity. In other words, the scale advantage of large central plants is overwhelmed by the cost of new transmission and distribution.

But this is only part of the story. The fourth column of Table 9.1 introduces two further, very significant capital cost penalties associated with central power generation. Line losses averaged 9% in the United States in 2004, but the losses during peak loads were much higher. In general, line losses vary with the square of current flow and with ambient temperature, and are thus much higher during the summer when wires are hot and electric loads are high. Peak period line losses from remote generation plants range from 20 to 30%, depending on the system and the distance that the power travels to users. In the last rate case approved by the Massachusetts regulatory commission, the utility serving Boston claimed peak period line losses from generator to consumer of 22%. If we assume that this line loss during peak periods is typical, then providing one kilowatt of new peak load will require 1.22 kW of new central generation capacity and 1.22 kW of new T&D capacity. By contrast, net peak period line losses from local generation are about 2%. If a local plant generates power in excess of site needs, that power flows backwards towards central generation plants, which reduces system line losses.

The need for redundant capacity also penalizes central generation. The North American Electric Reliability Council (NERC) has set a standard of 18% for reserve generation. By contrast, a recent Carnegie Mellon study found that a system comprised of smaller generation units would achieve the same reliability with only 3–5% redundancy (Zerriffi, 2004). Thus, as the percentage of total load generated by local CHP generators increases, the overall need for spare generating capacity and for spare T&D will diminish.

Hurricane Katrina drove these lessons home in 2005. The Missouri Baptist Medical Center was the only operational hospital in Jackson, Mississippi, for 52 hours after the storm, powered by its on-site CHP plant. Meanwhile, the grid could not deliver power to other area hospitals, and lives were lost.

To account for peak line losses and redundancy needs, Table 9.1 shows that delivering a kilowatt of new peak load requires either 1.44 kW of new central generation and T&D or 1.07 kW of new local generation. The last column presents the full investment cost of serving one kilowatt of incremental peak load with central or local generation. Central generation requires 228% more capital investment than local generation.

We can extrapolate to determine the annual capital cost penalty of continuing to serve U.S. electric load growth with central generation instead of local CHP power plants. The U.S. electric load currently grows about 14,000 MW per year. Serving load growth with central generation will require $46 billion capital investment for new central generation and wires or could be built for $20 billion with local generation, saving $25 billion investment each year.

9.1.2.1 Generation options for the future

We now examine future generation options for serving load growth and seek best options. Ideal options will generate and deliver power to consumers at prices below what they pay today. Ideal options will use no fossil fuel and emit no greenhouse gases. To find these generation options, one must answer a question – what retail price per kWh must be paid to cover all of the costs of generating and delivering the power, including capital amortization, peak line losses and system redundancy requirements?

The vertical axis of Figure 9.3 depicts the cents per kWh that must be paid by industrial customers to cover all of the costs noted above. The horizontal axis

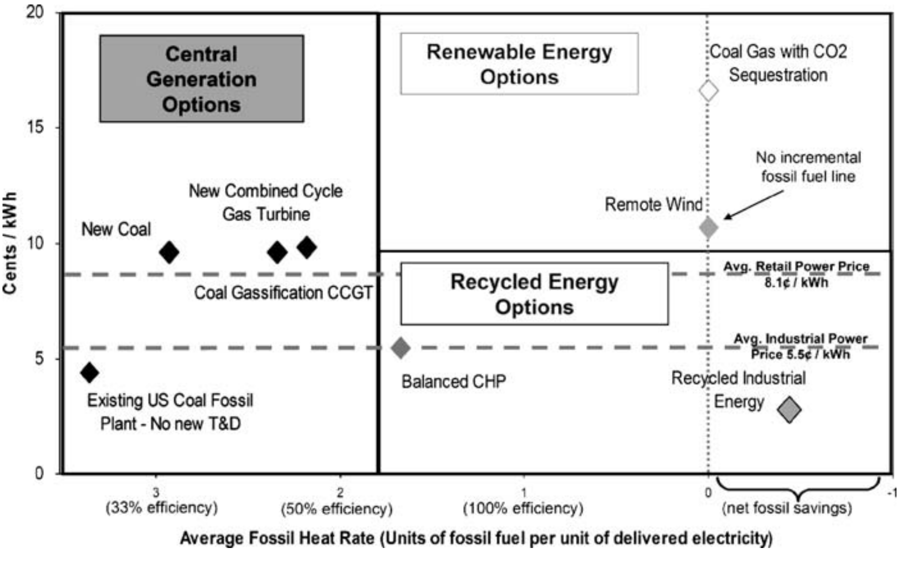

Figure 9.3. Future generation options

tracks fossil efficiency by showing the net fossil fuel required per delivered unit of electricity, all in the same units. A line is drawn at 5.5 cents per kWh, the 2005 average U.S. price paid by large industrial consumers, and another line is drawn at 8.1 cents, the 2005 average price paid by all retail consumers. This allows the reader to see which generation options will raise electricity prices and depress economic growth, and which generation options will lower electricity prices and accelerate economic growth.

The overall picture suggests cause for alarm. All conventional options will raise electricity prices. Small improvements in fossil efficiency come at a high price with new coal and gas fired central stations. The renewable energy options deliver a unit of electricity without burning any fossil fuel but raise delivered power costs even more.

We can see that a new conventional coal plant, after paying for emission controls and new T&D, will require 9.6 cents per delivered kWh, a 20% increase over today's average retail prices. Electric utilities and many policy makers are touting a new approach to cleaner and more efficient generation with coal, cleverly marketed as "clean coal." This new approach involves gasifying the coal first, which is a complicated, capital-intensive process, often referred to as Integrated Gasification Combined Cycle (IGCC). The process removes all of the sulfur and mercury in coal and produces a gas that can be burned in a gas turbine. By combining two cycles, making steam with the gas turbine exhaust to drive a second power turbine, the overall efficiency, net of gasification losses, can climb to 45%, half again as efficient as the 30% efficiency of conventional coal plants. But the process does not lend itself to smaller, local generation that could recycle waste heat. So, half of the energy in the original coal must still be vented. The current expectations for cost and performance suggest that combined cycle plants with gasification will require the same 9.6 cents per delivered kWh of new coal plants, an 80% increase over current average industrial prices.

Another option is to separate the carbon dioxide in the exhaust and then sequester the CO_2 in an underground cavern, or pump the CO_2 into an oil field or into the deep ocean (a process known as carbon sequestration). This option is being hailed by the power industry as a way to mitigate climate change. The Electric Power Research Institute (EPRI), which performs much of the research for utilities, has estimated that sequestering CO_2 will add 7 cents per kWh to the cost of power from a gasifier- based power plant.[10] Gasification is an essential first step to CO_2 sequestration, because the process separates the carbon dioxide from nitrogen that makes up roughly 80% of typical exhaust. Without the gasification step, the volume of gas to sequester would be five times greater and would not be suitable for enhanced oil recovery, which is one use of the separated CO_2.

Although this integrated gasification combined cycle plant still consumes over two units of coal for every unit of delivered electricity, it is depicted on the chart as zero fossil fuel, given that its greenhouse gas emissions have been sequestered. This is a way to produce clean energy, but it results in price increases of 100% over current average retail prices.

Combined cycle gas turbine plants are inherently more efficient than thermal plants and can deliver one unit of electricity with only two units of fossil fuel, but these plants burn expensive natural gas. Delivered power, from these generators, at today's gas prices, will cost consumers 9.8 cents per kWh or 92% more than current average industrial prices. This choice is particularly worrisome, given the extreme volatility of natural gas prices.

Renewable energy options shine in terms of reducing fossil fuel. Wind, geothermal, and solar electricity generation use no fossil fuel. But the costs can be considerable as described in chapter 8 by Rodney Sobin (forthcoming).

This leaves society with a discouraging list of conventional and renewable generation options. The conventional options burn two to three units of fossil fuel per unit of power and emit associated pollution and greenhouse gasses. Using conventional options to serve load growth will increase the average cost of delivered power by 80% over 2005 average U.S. industrial prices and drive up CO_2 emissions. The cleaner renewable energy options have even higher costs. If society continues to meet load growth with only these options, the nation had better prepare for a major economic slowdown.

Happily, there are other options, namely local generation that recycles energy. Combined heat and power plants (CHP), burning coal or natural gas, can deliver a unit of power with incremental net consumption of roughly 1.5 units of fossil fuel, half of the current average for the United States. These CHP units cover all of their costs while selling power for roughly the current average industrial cost of power, or 5.5 cents per kWh. This is good news for the environment and for future load growth and at worst, neutral to the economy. CHP can serve load growth at today's prices and cut fossil fuel use in half. But this is not society's best first choice.

Recycling industrial waste energy streams is the best electric generation option, up to the limit of waste energy streams. Large energy recycling plants earn a profit from selling electricity at half of the average industrial retail rate. Smaller plants are more expensive, but will, in nearly all cases, be profitable at prices below the delivered cost of power from new conventional central plants. Energy recycling plants improve the industrial host's competitive position and help preserve manufacturing jobs. Amazingly, the environmental performance of recycled energy facilities is better than renewable energy. Chart 2 shows that recycled energy from industrial waste energy streams *saves* a half of unit of fossil fuel for each unit of delivered electricity. This may sound like a violation of the laws of physics, but is correct, as explained below.

The typical waste energy recycling plant starts with hot exhaust, like the Cokenergy plant shown earlier, or with a low energy content gas, such as blast furnace gas, that would otherwise be flared. These industrial waste energy recycling plants consume no incremental fossil fuel, while typically producing both electricity and process steam. High-pressure steam is used to drive a turbine generator, and then some of the steam is removed at a lower pressure to provide thermal energy for space heating or other processes, which displaces boiler fuel. These industrial waste energy recycling plants displace boiler fuel by the beneficial use of waste heat, largely left over after electricity generation. Crediting these plants with the boiler fuel they displace allows one to calculate the incremental fossil fuel used to generate electricity. Since waste energy recycling plants start with zero fossil fuel, and then displace a quantity of boiler fuel, the net fossil fuel chargeable to electricity is negative.

The bottom line is profound: recycling waste energy reduces pollution, saves fossil fuel, and cuts the price of electricity. And, unlike conventional fossil generation options, most of the money paid for heat and power stays in the local area, servicing capital and paying operators and mechanics. Sadly, many current policies drive the industry away from energy recycling.

9.1.2.1.1 Electric cost and CO_2 *policy choices* There are four possible outcomes of any policy choice with respect to electric cost and CO_2 emissions. Chart 3 reflects how CO_2 emissions and cost per delivered MWh of power will change depending upon the technology used to serve load growth. The "combined cycle" referred to in two of these choices refers to plants using two separate physical cycles to generate electricity as described earlier.

The center of the chart signifies today's cost per delivered MWh to users and today's average CO_2 emissions per delivered MWh. Each technology to serve electric load growth is shown in the appropriate quadrant.

The three technologies that are favored by the power industry today are shown in the upper right hand quadrant. All three are lose/lose approaches at today's fuel prices. Conventional coal with environmental controls, coal gasification combined cycle, and gas fired combined cycle plants will all increase the delivered cost of power and increase CO_2 emissions per MWh.

The only central generation technology available that could lower the delivered cost of power at today's fuel costs is a conventional coal plant with limited pollution controls, shown in the upper left quadrant. Building such dirty plants is probably not an option.

A number of technologies lower CO_2 emissions per delivered MWh, but increase costs, as shown in the bottom right quadrant. Remote wind, geothermal, nuclear, on grid solar power, and coal gasification with CO_2 sequestration all emit little or no CO_2 but cost more per delivered MWh than today's average retail prices.

The bottom left hand quadrant should be the focus of policy. These approaches are win/win, lowering CO_2 emissions and lowering cost per delivered MWh. These technology choices include (i) balanced CHP using any fuel, including coal, (ii) industrial waste energy recycling, (iii) off grid solar, and (iv) small hydroelectric generation.

Over time, technical advances will hopefully reduce the costs of wind, nuclear, and geothermal generation enough to move these approaches into the win/win quadrant. With some modest technical improvements, on-grid solar could be cheaper than the on-peak power it replaces.

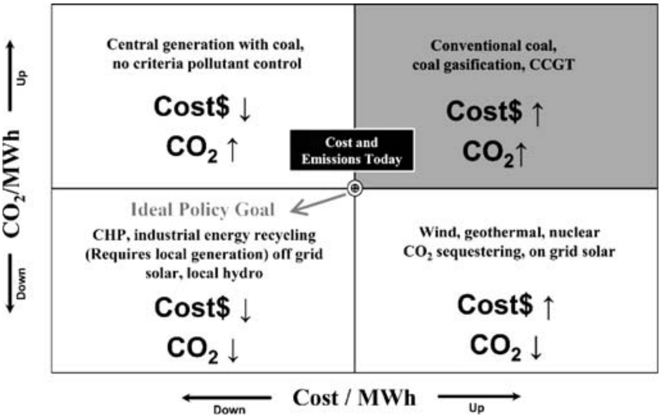

Figure 9.4. Electricity cost and CO_2 policy choices

Figures 9.3 and 9.4 assume that present energy subsidies continue (see section 9.3.3.2.1, "Energy subsidies are the rule"). Wind power receives a 1.8 cent per kWh production credit, but a variety of other subsidies applies to conventional fossil fuel power generation.

We have a problem. Present energy regulations drive the power industry to satisfy load growth with lose/lose technologies. Furthermore, existing regulations are filled with barriers to the local generation technologies that are win/win approaches. Until regulations are modernized and barriers to efficiency are removed, the power industry will continue to make deeply suboptimal choices.

9.1.2.1.2 Energy recycling development requires more skilled people Developing local CHP generation and industrial energy recycling requires more skilled people than developing new centralized plants. The same people skills and time needed to develop a 10 MW recycled energy plant could develop a 500 MW central plant. Each new electric generating plant development requires site acquisition, engineering design, permits, procurement, construction, commissioning, and financing. These are high-skill, high-value jobs and experienced people are in short supply. Furthermore, developing local CHP plants requires mastery of the host facilities' thermal energy needs and/or their supply of waste energy streams. Local CHP plants do not proceed to construction until the developer negotiates complete commercial terms with the host facility, a complication missing from the development of centralized generation plants.

One might think that it would take more operators and mechanics to run a system of multiple local CHP plants than to run a system of larger centralized plants. If this were so, local generation, which clearly requires more people to develop, would also require more operators and thus increase the labor costs embedded in each kWh of electricity. But limited data suggests the reverse; local CHP generation has labor productivity advantages over current centralized generation. The U.S.

utility industry employed 409,000 people in 2004, or 39 persons per 100 MW of generating capacity.[11] This may exclude some outsourcing of utility functions. By contrast, analysis of Primary Energy's employment data for 13 local CHP plants shows the company employs only 25 persons per 100 MW of capacity, thus achieving higher labor productivity than the operators of centralized generation, transmission, and distribution. Local generation does not need added transmission and distribution and the related T&D employees, whereas the centralized U.S. electric power system employment included 17 persons dedicated to T&D per 100 MW of generation capacity.

Utilities and their regulators see the need for more human resources to develop new generation, as well as the added complexity of understanding and negotiating commercial arrangements with the thermal host/waste energy supplier as a negative feature of local CHP. From the perspective of a power industry executive, local CHP generation is fraught with complexity that would overwhelm existing staff. In fact, a move to local CHP generation could reduce the value of the central generation plant development skill sets that have taken decades to master, just as the move to personal computers devalued skills of some corporate IT managers who had cut their teeth on mainframe computers.

From the regulators' perspective, changing governance to induce the power industry to construct multiple small plants will either vastly increase regulatory complexity, or more likely, will enable the market to perform much of the regulator's job. Either outcome frightens some regulators.

But adding high-skill development jobs to reduce power costs and related emissions would be positive for society.

9.1.2.2 World power system choices

How much capital investment will be squandered continuing to embrace yesterday's centralized generation approach instead of satisfying expected load growth with new local CHP plants? A recent study by the World Alliance for Decentralized Energy (WADE, 2005) extended the above analysis to determine the costs of supplying world electric load growth through 2030, and compared the two "bookend" or extreme cases of all centralized generation or all local generation to serve the world's expected electric load growth. The International Energy Agency (IEA) base case for 2030 assumes the addition of 4,370 GW of new electric load (4.4 billion kW). Using current capital cost estimates for the likely mix of generation plants, WADE found that the expected increase in electricity demand would require worldwide capital outlays of $10.8 trillion to supply expected load growth by 2030 with central generation. On the other hand, supplying the increased demand with local CHP plants would require capital outlays of only $5.8 trillion. The local CHP generation approach would thus save the world $5.0 trillion of capital.

This analysis of power system choices suggests that the United States and world power systems have not made optimal choices and that these poor choices have increased fuel use, pollution, and the cost of delivered power. Furthermore, the centralized approach has strong, negative impacts on the environment, grid reliability, and economic growth versus a more optimal system. Yet, the myth that world power systems are economically and environmentally optimal, given current technology, lives on and informs policy decisions. To understand the perpetuation of this myth or "mindset," we turn to an analysis of power industry governance.

9.2. PART II: UNDERSTANDING POWER INDUSTRY GOVERNANCE

9.2.1 Conventional Thinking versus Free Market Economics

If the above analysis is correct, why then does nearly every country continue to build new centralized generation when local CHP plants are more efficient and less polluting, require half of the capital, and reduce system vulnerability to weather and terrorism? Is this analysis flawed, or is there a flaw in conventional thinking?

Facts suggest the latter. The power industry will not make economically optimal choices until all players face true competition. This is especially so for those entities distributing electricity. The record shows that the regulated power industry has shunned local CHP generation. Between 1970 and 2003, U.S. regulated utilities, including government owned utilities, built 435,000 MW of new generation. An incredible 99% of this new capacity came from centralized plants that cannot recycle waste energy streams in lieu of fossil fuel (see Figure 9.5).

U.S. independent power producers built 175,000 MW of new power in the same period, of which only 34% is able to recycle waste thermal energy. The independent power companies largely stopped developing local CHP plants after 1992 when the federal law was changed to allow non-utility generation that does not recycle energy. The power industry has been able to avoid the complexity of developing multiple small plants that must interface with user waste streams or user thermal requirements, because local competition is largely blocked by power industry regulations. Without more open competition and/or mandates and incentives, the power industry

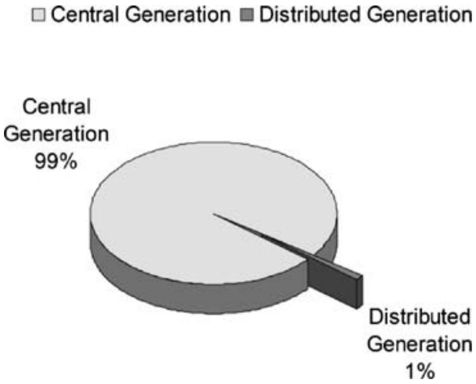

Figure 9.5. 435,000 MW New Generation Built by U.S. Electric Utilities, 1973–2002 (EIA, 2005)

will continue to build central generation and discard waste energy. Few power executives in either regulated or unregulated power companies relish the complexity of building many small energy recycling plants, even though these plants would reduce power costs and pollution.

9.2.1.1 Governance preserves waste

In competitive free markets, such suboptimal behavior would be an entrepreneur's dream, promising rich opportunities for profits. Entrepreneurs would actively search for ways to capture market share by offering better value propositions. But current power industry governance blocks competition from local generation.

The most important barrier to competition, as mentioned earlier, is the universal legal prohibition against private electric wires crossing public streets. This ban is supported by a century-old "natural monopoly" argument. According to the original economic theory, it would be a waste of resources to build two sets of electric wires. Consumers should thus benefit from governance that gives one organization a distribution monopoly in each geographic territory. This same "central planning" logic wrecked the Soviet economy, yet seems to go unchallenged in regard to electric power system governance. The good news is that monopoly-protected wires are just about the last vestige of failed central planning. The bad news is that the ban on private wires virtually guarantees continued mediocre performance of the world's largest and most important industry.

If restricting private wires ever made sense, which is doubtful, the logic had to be based on yesterday's limited technology choices. Electric distribution might be a natural monopoly if the only way to produce power economically was in large remote central plants, in which case all electricity would then have to flow through the distribution wires. But today there are abundant, proven ways to generate electric power locally. In fact, local generation uses substantially the same technology and same fuels used by central plants. Local generation needs no long-distance transmission systems to deliver power to users, and excess power produced locally could simply flow across the street. Regulations typically allow private pipes to transport excess heat across public streets to nearby users, but ban private wires from moving excess power across the same street. Local CHP power, using modern technology, could and would compete with central power if laws allowed private wires.

Consider the example of the McCormick Place Convention Complex in Chicago, Illinois, which is North America's largest convention center. In 1991, Trigen Energy Corporation won a bid to supply heating and cooling to the three large halls and could have cogenerated roughly 20 MW of electricity, or two thirds of the McCormick Place load, and then recycled waste heat from power generation to supply all of the heating and cooling needs (using heat driven absorption chillers). This would have produced electricity at a net efficiency of 80%, more than double the 33% national average. But the power plant site was separated from the convention center by local commuter rail lines that belong to the city of Chicago. Illinois, like every other state, prohibits electric wires that use (cross) facilities of the state or any subdivision thereof. This banned Trigen from crossing the rail right of way with a private wire to supply discounted electricity to McCormick Place. Commonwealth Edison, the local utility, offered to purchase the power for 20% of the retail price, which was not economic, so the heating plant was built without the efficiency of combined heat and power.

The bans on private wires are supposed to reduce societal costs by preventing the wasteful construction of duplicate wires. Ironically, the bans dramatically increase society's overall investment in wires. Remote power generation requires long transmission wires, transformers, capacitance banks, and inductance banks, which local generation avoids. The universal bans on building cheap, short local wires leads to the construction of expensive, long transmission wires. Electric customers pay for these extra wires.

Another flaw in governance is the well-documented and probably inevitable capture of regulatory agencies by the industry they regulate (Lowi, 1979). Regulators come to believe it is their job to protect the financial health of the monopolies they regulate, even if their decisions hurt consumers. A stunning example can be found in recent California experience. When a series of governance blunders threatened utility financial health, the state of California set out to purchase the transmission wires to save the utilities from bankruptcy. In the end, the state did not purchase the wires, but they did end California's four-year-old experiment that allowed local CHP generators to run wires to adjacent electric power users. California chose to go back to the future.

Allowing everyone to build private wires would not result in a tangle of new wires. If a local power developer has the right to sell power via private wires to neighbors, the local distribution utility will offer competitive prices to move that power in their existing wires. This is precisely what happens in natural gas distribution, where private pipes are allowed to tap transcontinental natural gas delivery pipes. When gas users receive Federal Energy Regulatory Commission (FERC) approval to tap the interstate pipe, the local gas distribution companies knock on their door and say, "Let us reason together." Deals are then made that are good for both parties. With the ban on private wires removed, the electric distribution utility might even decide to compete more fully by offering local CHP options to customers. Competition would work its usual magic, reducing consumer prices and wringing inefficiencies out of the system.

Instead, regulated utilities are regularly allowed to discourage local generation. In June of 2006, Pacific Gas and Electric was allowed to offer a "cogeneration deferral agreement" intended to defer the construction of customer cogeneration facilities, which would "uneconomically" bypass PG&E's electrical facilities (PG&E).

Experiments with deregulation have mostly focused on opening competition among central plants, not realizing that this is like "clapping with one hand." This approach to deregulation assumes that the only viable competition will be from other remote, centralized plants. But a power entrepreneur cannot truly compete without the unfettered ability to deliver product to customers. The private wire prohibition blocks competition from local CHP generation.

Another example will illustrate this point further. Primary Energy is a company originally formed in the early 1990s to develop, build, and fund projects that recycle waste energy in Northern Indiana steel plants. In 2000, the company expanded to offer similar services all over North America. Today, the firm owns and manages 13 energy recycling projects with cumulative generation capacity of 780 MW of electricity and 5.0 million pounds of steam. The company's Chair and CEO is one of the authors (Casten). In 2002–2003, Primary Energy was developing a facility to recycle the waste gas produced by a carbon black manufacturer in Louisiana. The carbon black plant flared enough low-grade fuel to generate about 30 MW of electric power. The new energy recycling plant would be expensive, costing over $50 million, but with no fuel cost, the plant could sell power at a discount to retail prices and still earn a profit. Permitting was easy because the EPA recognizes that boilers burn waste gas more cleanly than flares, thus reducing pollution. The potential project was designated a pollution control device.

The carbon black facility that produced the waste gas required only 10 MW of electricity – one third of the recycling facility's output. The carbon black plant paid the local utility roughly $55 per MWh (5.5 cents per kWh). They agreed to purchase their power needs from the recycling facility for $40–45 per MWh, saving $10–15 per MWh, or $800 thousand to $1.3 million per year. The project economics depended upon the sales price for the remaining 20 MW of recycled energy.

There was another industrial facility across the road, less than one half mile away, which also purchased power for $55 per MWh, and could have saved over $1.6 million per year by purchasing power from the recycling facility for $45 per MWh. **However, moving the electricity from the recycling facility across the street to the second factory was and is illegal; private wires are banned in Louisiana, as well as in the other 49 U.S. states**. The only legal outlet for the excess power was sale to the local utility. The astute reader may sense the next step.

The utility initially offered to pay Primary Energy $20 per MWh (2 cents per kWh). After one year of negotiation, the utility upped its offer to a princely $28 per MWh, roughly half of the retail industrial price. Accepting such a low rate would have required the energy recycling project to charge higher rates to the carbon black factory and probably killed the deal. So the Primary Energy developers kept negotiating. The team met the Governor, pointed out the job benefits of the project, and asked him to intervene and require the utility to pay fair prices. The intervention, after much delay, bore some fruit, causing the utility to raise its offer to $38 per MWh. But 2 years of negotiations had, by then, taken a fatal toll. The carbon black company developed deal fatigue – lost interest in more delays – and the development was stopped. Four years later, the carbon black factory continues to flare its gas. Over one billion kWh of fuel-free electricity have been lost in those 4 years.

But the story is not over. The utility has since been granted approval by the regulatory commission to build new transmission lines and to build a new central generation plant to serve this area's growing load. The new investment will raise every customer's electric rates and increase local air pollution. These rate increases and wasted fuel would all have been avoided, but for governance problems.

Many other regulatory barriers that block local generation could fill another chapter. Instead of detailing each barrier, we look briefly at how governance can encourage more optimal power industry behavior. We divide the answer into two parts, beginning with a theoretical economic approach, followed by suggestions for gradual changes.

9.2.1.2 Guidance from economic theory

Economists offer clear guidance on how to stimulate innovation and drive any industry towards optimal production: *expose that industry to market forces*. To work well, markets require:

- Free entry and exit into the business (i.e. no barriers to entry, no subsidies to prevent failure)
- Prices that send clear and accurate cost signals
- No subsidies that distort pricing decisions
- Externality costs be passed on to customers
- Predatory practices be prohibited.

No power industry governance in any territory in the world embodies all of these conditions. Consider typical power industry governance:

9.2.1.2.1 Entry is blocked Partial deregulation has allowed new entrants to central power generation, which has reduced some waste. But governance everywhere has continued to enforce local distribution monopolies and left incentives for local utilities to block local CHP generation. To compete, entrepreneurs must be allowed to build local power plants. Limiting competition to central generation is like allowing new competitors in a foot race but only if they have their feet tied together.

Governance rules seldom ban local CHP generation. However, various rules prevent local power plants from capturing all of the value they create and block development. Although some local CHP projects struggle past all of the obstacles and are built, most die before birth. A local generation plant displaces the host's purchased power at retail prices, which include costs of transmission, and thus can capture some grid displacement value. But regulators then allow excessive standby rates that take the value back. Excess power can only be sold to the grid at wholesale prices, even though all excess power automatically flows to nearest neighbors, who are then forced to pay retail prices.

Example: Sugarcane factories all over the world typically burn the cane residue, called bagasse, in old and inefficient power plants that generate only enough electricity and steam to meet the sugar mill needs. The rest of the bagasse is simply incinerated – its energy content is wasted. Local utilities, which are often government owned, either refuse to purchase power from local producers or offer only a small fraction of retail power prices. Such prices make it uneconomic for the sugar mills or third parties to invest in power generation that exceeds the sugar mill's needs. This is a terrible waste, because a modern power plant would convert the bagasse into three times the electricity needed by the sugar mill and thus supply power to the surrounding rural area. When local utilities have been forced to offer fair prices, the sugar industry has built new plants that efficiently recycle the remaining energy potential in the bagasse. Recent regulatory changes in India have induced 87 sugar mills to construct over 750 MW of new recycled energy capacity, and are expected to call forth 5,000 MW of recycled energy over time, which would be roughly 5% of India's present generation capacity (Natu, 2005). The resulting power is pristine, burning no incremental fuel (the bagasse would have been burned for disposal anyway) and emitting no incremental pollution.

9.2.1.2.2 Energy price signals are misleading Functioning markets depend on accurate and timely price signals, but electricity is typically sold at average prices, even though marginal costs are up to ten times higher during peak hours than during off peak hours. Real-time pricing would cause consumers to conserve and shift some power use to off peak periods, reducing system peak loads and reducing the average cost of electricity. Real time pricing would signal power entrepreneurs to develop new on-peak generation and to store energy during off-peak hours for on-peak use. Prior to the explosion of computer technology, the cost of metering use in real time was expensive and limited to large industrial customers. For the past decade, the power industry could purchase and install relatively cheap meters that record real time use and receive signals over the electric wires with the instant marginal price of power. However, little has been done to modernize the method of selling power in real time.

Example: California's electric system peak is nearly 50,000 MW, which strains the grid and has caused frequent brownouts. California consumers, seeing only average prices, use 1,000 MW of power during peak hours to wash their clothes.[12] Accurate price signals would allow these consumers to reduce their electric bills by washing clothes during off peak hours, and might induce appliance manufacturers to add smart controls to washers and dryers, which would automatically shift loads.

9.2.1.3 Energy price signals, part two

In 1978, Congress enacted the Public Utility Regulatory Policies Act, or PURPA, to promote more efficient generation. Third parties were allowed to own and operate power plants that combined generation of heat and power, providing the facility met certain efficiency tests or recycled energy streams left over from some industrial process. We refer to these "bottoming cycle" plants as industrial waste energy recycling facilities. Such facilities were termed "cogeneration" and were exempted from Federal Power Act regulations. PURPA refers to all of these facilities as "qualified facilities" or QFs for short.

PURPA requires states to cause utilities to purchase power from qualified facilities at the utilities "avoided costs" or such other arrangement that each state felt would induce construction of more efficient plants.

Much can be learned about the power industry by studying the responses to this 1978 law. Regulated utilities objected and have generally worked ever since PURPA's enactment to blunt or repeal the law. One group of utilities repeatedly challenged the law's constitutionality, and appealed three separate cases all the way to the U.S. Supreme Court. The Court found PURPA constitutional in all three cases, with the last ruling in 1984. These cases nearly stopped entrepreneurs from cogeneration development prior to 1984.

State administration of PURPA varies widely. Some states enthusiastically embraced PURPA and set arbitrary prices for "avoided costs." New York initially offered QF facilities 6 ¢ per kWh, while Maine offered 10 ¢ per kWh. In other cases, commissions asked the regulated utilities to specify what plant they would build as the next electric generating unit, and then used the economics of that plant as a bogey for avoided costs. Some states did nothing. In the 28 years since PURPA enactment, we are unaware of any contract ever issued to a QF in Louisiana, South Carolina, South Dakota, or Kentucky.

The utilities have worked hard and often successfully to emasculate PURPA by persuading their commissions to set "avoided costs" that only cover short run avoided costs. These short run avoided costs only cover fuel and incremental maintenance while ignoring longer term costs of capital amortization, T&D construction and losses, and system redundancy requirements. Commissions have been asked to believe that wholesale power market competition will drive electric wholesale prices down until they just cover short run incremental costs – fuel and marginal operating costs. Since no one can afford to build new generation for only wholesale spot prices, no CHP is built, and society then pays higher prices for central power.

The most revealing part of the 28-year PURPA history is the way commissions have determined the costs that new local generation plants would avoid. By and large, the analysis has been limited to the avoided generation costs. To be of use to customers, power must be generated *and* delivered. Local generation avoids most T&D, line losses, and redundant capacity costs and should receive value for avoiding these costs. But state regulatory commissions have typically approved "avoided costs" that do not include savings due to avoided T&D capital or avoided T&D losses. These rates prevent new CHP plants from receiving the full value they create, thus limiting CHP development. This failure to ask the right question – what is the delivered cost of power for each option – goes far to explain the continuing reliance on suboptimal central generation.

A current example demonstrates how such governance fails to produce economically rational power industry decisions.

9.2.1.3.1 Case study: recycling energy from silicon production Silicon metal is used in over 2500 products from bathtub caulk to aluminum alloys to computer chips and solar collectors. Current world production of metallurgical grade silicon is about 3 million tons per year, of which only 300 tons or 10% are produced in the United States. Silicon production is energy intensive; energy represents one third of total production costs. Quartz rocks, coal, charcoal, and wood chips are continually fed into smelters, which are then heated to 3000–5000°F by electric furnaces. For obvious reasons, silicon factories are located in low priced electricity territories.

It is technically feasible to recycle energy in the hot exhaust from silicon smelters and generate nearly one megawatt-hour of fuel-free electricity for every two megawatt-hours of electricity used by the smelter. The waste energy stream of hot exhaust comes from the electric arcs as well as from burning coal, charcoal, and wood chips. Typical silicon factories use 40 to 120 MW for smelting and could thus produce 20–60 MW of fuel-free power by recycling hot smelter exhaust.

Now, our story gets interesting. New energy recycling facilities for silicon smelters are expensive, costing $1,800–2,000 per kW of capacity. The recycling facilities need to sell electricity for $35–45 per MWh to cover operating costs and repay the capital investment. This compares favorably to $55 per MWh charged to the average U.S. industrial customer and $96 per MWh for the cheapest new central generation, so there would seem to be an economic logic to building these recycling plants. But the silicon plants are located in low-cost power areas such as West Virginia and Alabama, where they currently purchase power for $30–35 per MWh. Thus a silicon factory could lose money if it built a recycling facility only to displace its own purchased power.

Is this a good outcome for society? Is it good policy in Alabama or West Virginia? We think not, for the following reason. Electric power demand is growing in both states. As shown previously, the lowest delivered cost of power from new central plant options will be roughly $96 per MWh. Both states would clearly benefit from meeting load growth with energy recycling facilities that deliver electricity for $35–45 per MWh.

Under current regulatory policy, this will not be the outcome. As we have seen, the recycling plant is not economic if it simply displaces $30 retail power. This leaves no savings for the silicon factory and thus no reason for them to develop energy recycling. If the recycling plant developer seeks to sell power to the grid, the local utility will claim it can purchase wholesale power on the spot market at even lower prices: regulators seldom intervene in favor of higher prices.

Current utility actions all over the United States illustrate the problem. Utilities are asking and receiving permission from regulatory commissions to build new coal plants that will go into rate base. For example, the Colorado Public Service Commission authorized Xcel Energy to construct a new coal plant to meet load growth. The construction costs, including elaborate pollution control equipment, will go into the rate base. The plant will require added transmission lines, which will also go into rate base. After 2009, when the plant is expected to be completed, Xcel Energy will ask for rates that recover all of the fuel and operating costs, all of the capital amortization, including T&D and sufficient profit to generate the allowed rate of return. At that point, the new T&D will be seen as a sunk cost and not be included in prices to local CHP plants, ensuring inefficient future generation.

The regulators apparently examined the average cost for power from the proposed new coal-fired plant without considering T&D capital and losses or redundancy needs, because the same commission allows Xcel Energy to offer only the prior years average coal cost per MWh to CHP plants. Primary Energy owns a CHP plant in Greeley, Colorado, and all 85 MW would be consumed in the Greeley area, freeing transmission wires. The commission allowed Xcel Energy to offer only $12 per MWh to this CHP plant in 2005, but also allowed Xcel Energy to build a new coal plant that will require an incremental $90–100 per MWh to deliver power to Greeley. Regulatory commission analyses, by ignoring power delivery costs, typically conclude that it is prudent for the utility to build a new central plant, even though local CHP provides a significantly cheaper option.

Sadly, this story has been the norm for many years. Most of the time the governance system ends up choosing suboptimal central generation to serve expected load growth. In the instant case, average rates to consumers will increase and Colorado's energy intensive factories may even close, unable to compete with foreign production. The new central generation plants will burn three units of coal or natural gas for each unit of delivered power, with associated carbon dioxide emissions. Everyone but the utility's shareholders loses. So far, political leaders have responded to pressure to limit greenhouse gas emissions by appropriating taxpayer funds to subsidize renewable energy capacity, which will further increase electric rates, but lessen pollution.

Everyone's goal should be a system of regulation/free markets that permits (better yet encourages) the maximal deployment of recycled energy plants. The outcomes would then be very different: average power costs would fall, air pollution including greenhouse gasses would fall, and manufacturing competitiveness would improve.

9.2.1.3.2 Energy subsidies are the rule Subsidies of any product distort price signals and lead to suboptimal investments. But this undisputed economic fact is honored in the breach in the global energy industry. All over the world, politicians have responded to citizens' desires for cheaper energy by subsidizing various parts of the energy system. These subsidies, which are paid out of tax revenues, buy down electric prices to consumers and thus signal those consumers to overuse energy and to under-invest in conservation and efficiency.

Example: State and municipally owned power systems, unlike other manufacturing enterprises, pay no income tax and are allowed to issue tax exempt and/or taxpayer-backed debt with interest rates well below those paid by competitive industries. Tax credits for wind, solar, geothermal, and biomass power generation subsidize power from these technologies. These subsidies hide the true cost of electricity, encouraging waste. Consumers collectively pay for all the subsidies, because governments must tax other activities to make up for lost revenues. But the subsidies lead to many suboptimal decisions that increase the cost of heat and power. Although energy subsidies represent a true "lose/lose" policy, they are nearly universal.

Second Example: The 2005 U.S. Energy Policy Act (EPACT) gave a bonanza to the oil and gas companies who leased blocks of drilling rights in U.S. territorial waters in the Gulf of Mexico. A provision in the law waived the royalty payments for oil produced on federal property in the Gulf of Mexico, even though such payments are required for oil produced on all other federal property. In other words, EPACT said to the oil companies, "You may extract the oil from these federal lands without paying anything to the federal government." The New York Times estimated this subsidy will cost taxpayers between $7 and $28 billion over the next five years (Andrews, 2006). The subsidy does very little to help the American consumer. The lease-free oil either increases oil company profits or finds its way into the world price of oil, and the subsidy is thus dissipated over the worlds' oil consumers. But the loss of revenue must all be made up by U.S. taxpayers. To the extent this subsidy of oil companies lowers oil prices, it obscures the true cost of using oil and gas, thus making investments in energy efficiency less attractive than their true economic impact.

9.2.1.3.3 Externality costs are not included in energy prices Businesses and consumers typically ignore the costs of externalities unless these costs are included in the product's selling price. Fossil fuel taxes seldom cover the externality costs of burning fossil fuel, thus understating energy costs.

Example: Societies pay health costs caused by pollution from burning fossil fuel with tax-supported Medicare, health insurance, and individual medical bills. For instance, the Transboundary Air Pollution panel has concluded that air emissions cause $6.6 billion per year of added medical costs to the citizens of Ontario, Canada. None of these costs is paid for by taxes on fossil fuel use, which is the source of the harmful emissions. Other taxpayer funded programs pay to remediate acid rain damages. Recent legislation seeks to mitigate climate change caused by fossil fuel emissions with taxpayer-funded programs. These actions, by using tax dollars to pay for the externality costs of burning fossil fuel, hide the true cost of energy from energy users. Taxing fossil fuel to recover the estimated externality costs would increase the cost of electricity and stimulate investments in efficiency. These taxes could be made revenue neutral by lowering other taxes. Because European countries tax fossil fuels more heavily than is the case in North America, Europeans have invested heavily in energy efficiency. Typical European countries produce a dollar of gross domestic product with half of the fossil fuel that is used to produce the same dollar of GDP in the United States.

9.2.1.3.4 Predatory monopoly practices are protected by law Dominant incumbent firms can often afford to engage in predatory practices, offering products at below cost until the low prices destroy competition. The dominant firm can then raise prices to new highs and extract "monopoly rent." To prevent such predatory actions, governments have enacted anti-trust rules. These rules apply to nearly all business activity and help promote and preserve competition. But the anti-trust rules do not apply to electric utilities, which are allowed to engage in precisely the predatory practices that are banned in all other businesses.

Example: Many regulatory commissions allow electric utilities to offer discounted rates for "all electric" buildings that agree to use electricity for all heating, cooling, and lighting. This discourages non-electric heating and cooling systems that are more fossil-efficient. A large office complex that uses CHP for some of its power does not qualify for the "all electric" rate and thus pays a premium for the power they purchase from the grid. By contrast, when Kodak offered lower prices for copiers to those consumers who also agreed to purchase maintenance from Kodak, the Supreme Court held that this violated anti-trust statutes against product bundling. There are many other examples of predatory practices by electric utilities that are allowed by current power industry governance.

Power industry laws and regulations throughout the world thus ignore the lessons of economics. Without these minimum conditions, Adam Smith's "invisible hand" cannot work; the power industry continues to waste energy and capital.

9.2.1.4 Policy options to encourage recycled energy

We now move to suggestions for regulatory reform that would induce more optimal behavior. Changing power industry governance will not be easy, given the widely believed myths and the vested interests of a century of monopoly protection. Politicians risk unemployment when they propose to tax energy or to remove energy subsidies. The citizens who receive subsidized power inevitably band together to oppose any party or politician who threatens their subsidy. These efforts typically overwhelm the much larger and more diverse group of taxpayers who fund the subsidies.

Happily, there are some politically feasible first steps. Removing barriers to innovation and mandating clean energy are less politically charged than fully opening competition; such changes could be enacted. Small policy changes will deliver appreciable benefits to the public and create a case for further unleashing market forces to wring waste out of the worlds' largest and most important industry. The public has experienced problems stemming from poorly designed partial deregulation, such as occurred in California, but has not been able to enjoy benefits that true competition would produce. We suggest some first steps that will begin to develop full benefits.

Policy Change: Allow local CHP generators to build private wires to a limited number of retail customers, sufficient to transmit excess capacity. Alternatively, require commissions to set variable grid charges based on the distance the power will move and the relative tightness of the existing network. The simple "postage stamp" rates that are employed in most jurisdictions charge all generators the average cost of moving power across the state, which deny the transmission benefits it creates.

Policy Change: All state regulatory commissions modify the rules for utility returns on capital so the utility will not be penalized from loss of load to local CHP generation or from efficiency investments by customers that reduce electricity sold by the utility. At present, most rates are set based on a test case of presumed electricity consumption by each class of customers. If exactly that amount of consumption occurs, the utility should earn the allowed "target" rate of return on their invested capital. But if the consumption is less, due to conservation, local generation, or depressed economic performance in the area, the utility profits drop sharply. The inverse is also true and load growth is richly rewarding for the typical utility. The Regulatory Assistance Project (RAP) in Montpelier, Vermont, has crafted some innovative approaches that isolate the utility from lost profits due to conservation and local CHP generation. If enacted, such programs remove the misalignment of utility shareholder interest with societal interest.

Policy Change: Make recycled energy eligible for all Renewable Portfolio Standards (RPS). Many states and nations have recently enacted laws mandating that a growing percentage of power be obtained from a specified list of clean energy technologies. These rules usually limit eligibility to renewable energy, mistakenly assuming this is the only "clean energy" option. We suggest the rules also credit power recycled from industrial waste energy and credit thermal energy recycled from local CHP generation plants. Five U.S. states (North Dakota, South Dakota, Nevada, Connecticut, and Pennsylvania) have included recycled energy in their clean energy portfolio standards.

The U.S. Congress considered enactment of a national Renewable Portfolio Standard in 2001, but the measure, mandating that a growing percentage of power be generated by renewable energy sources (solar, small hydroelectric, wind, and certain biomass) met strong opposition for good reasons, and was not enacted. By requiring all states to obtain a growing percentage of their electric power from clean sources, but then limiting the definition of clean energy to power produced from renewable energy sources, the proposed law would have created a wealth transfer from most of the states to the 7–8 states with extensive wind resources. Wind, as shown above, is far cheaper than other sources of renewable energy. Wind would have been the "clean energy" of choice, forcing most industrial states to pay subsidies for wind power production in windy states. By contrast, every state has many opportunities to recycle industrial waste energy and to deploy CHP plants that recycle heat from electric generation.

An amendment to the National RPS proposal that included recycled energy was discussed with House and Senate leaders in 2001 and was well received, until several environmental activist groups ganged up and threatened to withdraw support for a national RPS if the bill made recycled energy eligible to compete with other clean energy.[13] The environmental organizations who opposed adding recycled energy wanted to cause development of renewable energy technologies at any cost and were fearful that recycled energy would undercut the premiums paid for renewable energy. The question of proper national goals is at the root of this conflict. Is the goal to produce more clean energy at the lowest possible cost, or is the goal to stimulate the development of certain types of clean energy technology? We suggest the goal should be to induce more clean energy at the lowest possible cost. Enacting a national "clean energy" portfolio standard that includes recycled energy should be politically feasible, since every state has the potential to recycle energy.

One objection to including recycled energy in portfolio standards bears further discussion. Opponents to including recycled energy in the RPS mandates point to a second political goal, namely to create new industrial clusters that will manufacture tomorrow's technology. Denmark's mandates for increased wind power created a strong local market for wind turbines, which enabled Danish firms to develop and sell world-class wind technology. We suggest that energy recycling is also an important future industrial cluster, with double benefits. Laws mandating more recycled energy will help entrepreneurs develop recycling technology for export, and will encourage existing local industries to recycle energy, thus improving their competitiveness.

Policy Change: Require grid operators to interconnect in parallel with backup generators, in return for the right to purchase power from those generators during extreme system peaks and emergencies. The United States has roughly 90,000 MW of standby generation installed in hospitals, prisons, critical industrial facilities, and high-rise buildings. This standby generation capacity is roughly equal to 12% of U.S. electric system peak. However, very little of this standby generation capacity is interconnected with the grid. In the typical arrangement demanded by the local electric distribution monopoly, the standby generators are required to be electrically isolated from the grid at all times. When the grid fails, the breakers open such that no electricity can flow to or from the grid, and then a second or two later, the breakers close between the standby generation and selected building emergency loads. When the grid returns to service, there is another power outage before reconnecting the building/facility to the grid. This clearly prevents the use of the standby generation to produce any of the power the facility needs while connected to the grid, and thus prevents the standby generation from helping to supply system peak electric loads.

When the grid is strained, very little of the 12% standby capacity can be used to avoid full system failure. In the August of 2003, transmission wires in the northeastern United States and Canada became overloaded and began to fail. System operators rerouted more power over the lines still in service and those lines either failed or were shut down by automatic safety devices. Over 50 million consumers lost power for 24–60 hours with incredible economic disruption and costs. If the utility regulators had demanded that all standby generation be interconnected with the grid, just like all of the centralized power plants, the utilities could have asked standby generators to turn on and ease the transmission overload, and the blackout would never have occurred. Using standby generation to shave extreme electric system load peaks would lighten grid loads, help avoid brownouts and blackouts, and save lives. Parallel standby generation could also, by shaving system peaks, avoid the cost of new T&D. But a building with parallel interconnections could and would use its standby equipment to shave expensive peak loads, cutting utility profits. Some utilities claim technical issues in their refusal to allow parallel interconnection. This change has great significance to local CHP development, which is often frustrated by the utility's refusal to interconnect in parallel with the grid.

Policy Change: Require utilities to pay local generators for the full value that such plants provide to the grid, including avoided capital cost for generation and T&D, saved line losses, reduced pollution, and grid voltage support. Utilities always ask regulators to approve charges to local generators to pay for backup service provided by the grid, which is reasonable. But commissions need to invert the analysis and ask utilities to pay local generators for the services these local generation plants provide to the grid.

A recent study conducted at the University of Massachusetts found that each kilowatt of new distributed generation installed in Boston would produce a *net* societal benefit of $351 per year (Kosanovic and Beebe, 2005). In other words, the savings of capital investment in the grid and the value of reduced line losses, less the costs to the utility of providing backup service to the local generator netted out to a value to the grid of $351 per year per kW of new capacity. Ignoring this study, Massachusetts regulators recently approved standby charges in Boston of $114 per year for each kilowatt of local CHP generation capacity. Regulators allowed a deal without a rate case that requires Boston CHP plants to pay an annual penalty of $465 per kW of capacity for the right to operate with grid backup (receive nothing for the $351 per year net benefit they provide and pay a $114 per year penalty) (Kosanovic et al., 2005). Not surprisingly, no one is building new local CHP generation in Boston.

Policy Change: Make carbon savings from recycled energy eligible for "green tags" and carbon trading credits. Many electric consumers voluntarily pay a premium for clean electricity but the choices are limited to renewable energy. Including recycled energy will increase clean energy production and reduce its cost.

Although these suggested policy changes are only a start, they will create significant benefits and weaken the centralized generation mindset. Then, perhaps, the political environment will allow more changes, including ending all energy subsidies and taxing the externality costs of burning fossil fuel. The business-as-usual approach will, as always, command great allegiance from incumbent firms who benefit from present rules. But the rapidly growing energy disaster requires dramatic change, fresh ideas, and political leadership.

9.2.2 The Stakes are Very High

We close this chapter with a warning that continuing the current power industry governance has dire consequences to the economy and the environment.

Continuing current power industry governance will, without doubt, accelerate the emission of greenhouse gasses and thus speed the global warming trends that are causing climate changes and disrupting the entire ecosphere. It makes no sense to block electric power innovations and cause excessive burning of fossil fuel, unnecessary carbon dioxide emissions, and high power costs.

Continuing the current power industry governance in the face of rising fossil fuel prices could not only stop income growth, but could even lead to declining per capita incomes. The long-term trends that have lowered the cost of energy services throughout the 20th century have stalled, threatening to disrupt economic progress severely. Average delivered electric generation efficiency has not improved significantly since 1959. Fuel prices are three to five times 1999 levels. Power quality is costing the U.S. economy nearly $200 billion per year according to a recent Electric Power Research Institute study (EPRI, online).[14] Transmission systems are strained, such that extreme weather conditions regularly disrupt electricity supply. Vehicle and appliance efficiency gains have slowed.

Continuing current power industry governance will exacerbate several other major problems. The centralized generation system is vastly more vulnerable to extreme weather conditions and terrorists than a system of local generation, and this vulnerability is being tested by the increasingly violent storms like Katrina and Rita of 2005, and the massive East Coast rains in June of 2006. Those intense and violent storms do not "prove" global warming but are consistent with climate scientist's prediction of weather changes from increasing average global temperatures. Senator Lugar of Indiana and former CIA Director James Woolsey estimated that the United States is spending $100 billion per year defending access to foreign petroleum and natural gas supplies, and these costs are exacerbated by the 17 quads of fossil fuel that are needlessly burned to produce heat and power in the United States. Finally, rising power prices exacerbate the loss of manufacturing jobs.

The stakes to the economy from energy efficiency may be much higher than generally realized, and a final comment is called for at this point. Though the full story is too complicated to tell here, there can be little doubt that productivity increases and economic growth in the past have been driven very largely by the use of fossil fuels to drive machines – notably steam engines and internal combustion engines (Ayres et al., 2003, 2005; Warr and Ayres, Warr, Benjamin and Robert Ayres. "REXS: A Forecasting Model for Assessing the Impact of Natural Resource Consumption and Technological Change on Economic Growth." *Structural Change & Economic Dynamics 17(3)* (September, 2006), pp. 329–378). These, in turn, have performed useful work (much of it electric) and substituted energy services for human and animal labor. For over two centuries these "engines of growth" have contributed to, and been driven by, declining fossil fuel prices and increasing efficiency of conversion of raw energy to "useful work" – especially to electric power.

But industrial societies are now dealing with sharply higher prices for petroleum, natural gas, and coal. Ubiquitous energy subsidies and the current energy governance stoke the demand for fuel and induce further fossil fuel price rises in ways described above. Outmoded regulatory policies force further increases in average electricity costs by demanding clean energy but restricting the supply to only renewable energy sources. The consequences, in the absence of a major structural change, could be reduced economic growth, extended recession, and declining standards of living. The stakes are high, and energy recycling with local CHP plants is the single most promising strategy for avoiding this threat.

Political leaders have failed to fix governance but have mandated higher energy prices for certain types of clean energy. We believe this strange behavior is explained by the assumption that the present energy system is economically optimal. This entire book shows the fallacy of the prevailing energy myths. The power system is neither economically nor environmentally optimal.

In a way, this is good news. To paraphrase Al Gore's new documentary, our findings are "Convenient Truths." Political leaders seeking to mitigate climate change, reduce fuel imports, and preserve jobs, have attractive choices. Indeed, society can "have its cake and eat it too." Demand clean energy and remove barriers, rule sets and mindsets, and power industry entrepreneurs will deliver clean, affordable, sustainable heat and power. By contrast, continuing with the century-old central generation paradigm will exacerbate climate change, slash economic growth, and lead to declining standards of living.

As shown above, the costs to the world of continuing to service electric load growth from centralized power plants that cannot recycle energy are very high. Spending $10.8 trillion to supply global electric load growth over the next 30 years with central generation will greatly worsen CO_2 emissions. Moreover, according to the International Energy Agency, business as usual will still leave over 1.4 billion people in a state of energy poverty (IEA, 2002, p. 3). The world would be better off to deploy local generation with doubled efficiency, save $5.0 trillion, and then use some of the savings to extend energy services to all people.

There is no reason to settle for current energy inefficiencies. *Energy recycling is economically advantageous using existing technology*. But because energy recycling requires massive human resources to develop, it will proceed slowly unless mandated, either by governments or by market forces. We believe the best way to improve energy system efficiency is for governments to heed the lessons of economics and fully expose the power industry to market forces. Failing such full deregulation, performance can be improved by eliminating regulatory biases against local CHP generation and by encouraging energy recycling. Once the public sees the benefits, support for more comprehensive changes will grow.

It should be emphasized that there is no need to eliminate existing central generation capacity. A great deal of new local generation is needed just to meet the world's expected electric load growth and cover retirement of the aging fleet of central plants. Nor is there any reason to weep for the established utilities. Nothing should prevent these organizations from participating in the inevitable (and profitable) new market for decentralized CHP plants that recycle energy.

It is time to challenge the widely held assumptions among economists and policy makers that central generation and monopoly protected electric distribution are optimal. Like Voltaire's *Candide,* these folks assume (contrary to evidence) that this is "the best of all possible worlds." Global economic and environmental health depends upon the speed at which governments stimulate economic efficiency in the world's largest industry: electric power production and distribution.

NOTES

[1] In a speech to the National Small Business Conference on 17 April, 2005, President George W. Bush said, "Technology is allowing us to better use our existing energy resources. An in the

years ahead, technology will allow us to create entirely new sources of energy in ways earlier generations could never dream. Technology is the ticket; it is this nation's ticket to greater energy independence."

[2] The US raw energy input in 2004 was 99.7 quads, of which 85.7 quads came from fossil fuel. Transportation, which is nearly all fossil fuel based, consumed 27.8 quads or 28% of total input energy. Of the remaining 57.7 quads of fossil fuel, we estimate that 5–8 quads were used as a feedstock for various chemical productions, and that the remaining 50–52 quads were used to produce thermal energy and electricity – heat and power. An optimal system that recycled waste energy streams would save 17 quads or 20% of all fossil fuel currently used (EIA, 2005).

[3] Proven technology using organic fluids in a Rankine cycle profitably converts exhaust gases with temperatures above 600°F to electricity (see www.ormat.com), while conventional steam cycles become cost effective at roughly 900°F. Promising technologies now under development could produce electric power with exhaust temperatures as low as 180°F, but these approaches require further capital cost reduction to be economically attractive in replacing current average cost electricity.

[4] At the end of 2004, 1800 MW of solar collectors were installed worldwide, which, at an estimated annual 10% annual load factor, would have produced roughly 1,600 GWh of clean energy. The 95 MW coke oven exhaust recycling plant produced 503 GWh of electricity and 1,140 GWh of process steam for a total of 1,643 GWh of clean energy in 2004, roughly the same amount of clean energy (REN21 Renewable Energy Policy Network, 2005).

[5] The $165 million energy recycling plant produced 9,960 kWh of clean energy per dollar of investment. New Solar PV at $8000 per kW and a 12% annual load factor produces 131 kWh of clean energy per thousand dollars of investment (assumes improved utilization versus existing fleet). The recycled energy plant thus produced 75 times more clean energy per dollar of investment than new solar. New wind costing $1,300 per kW plus $1,400 per kW for T&D will produce, at a 31% load factor and 9% line losses, 915 kWh per thousand dollars invested. The recycled energy plant thus produced 10.8 times more clean power than new wind per dollar of investment.

[6] All nuclear powered submarines and aircraft carriers recycle exhaust heat from the nuclear plant steam turbines for ship's thermal energy.

[7] Example: South Carolina Code of Laws, Title 58 – Public Utilities, Services and Carriers, Chapter 27, Electric Utilities and Cooperatives Article 3, Franchises and Permits, Section 58-27-40. Procedure for granting exclusive municipal franchises to furnish light, states, "All cities and towns of the state may grant the exclusive franchise of furnishing light to such cities and towns and the inhabitants thereof."

[8] The $890 per kW of capacity is a calculation from table 3.11: New Electricity Generating Capacity and Investment by Region, page 132, World Energy Outlook 2002, International Energy Agency, and is the IEA's estimate of the additional capacity that will be built worldwide between 2000 and 2030. The estimate of typical costs per kW of recycled energy capacity is based on internal cost records of Primary Energy, Trigen Energy Corporation, and Turbosteam. These companies are or have all been developers of recycled energy facilities managed by one of the authors (Casten).

[9] The grid peak occurs over 150 hours, roughly 2% of the year. The probability of all three generators randomly failing during grid peak is .02 × .02 × .02 × .02, or .00000014, one in 6.25 million.

[10] Personal conversation at EPRI, Planning Meeting from Steve Specker, President of EPRI, Fall 2005.

[11] http://permanent.access.apo.gov/website/www.eia.doe.gov/cneaf/electricity/epa/epa/epa.sprdshts.html and the labor data from http://data.bls.gov/PDQ/outside.jsp?survey=ce, then combined by the authors to calculate persons employed per megawatt of capacity.

[12] Comments from William Reed, Senior Vice President, Regulatory Affairs and Strategic Planning, San Diego Gas & Electric at the West Coast Energy Management Conference on 28 June, 2005.

[13] One of the authors, Casten, worked with the Senate Energy Committee in 2001 to craft the proposal to include recycled energy, and discussed the proposal with then House Commerce Committee Chairman, Billy Tauzin and others, with positive reception until the environmental groups persuaded Senators on the Senate Energy Committee to oppose the change.

[14] Electric Power Research Institute's Consortium for Electric Infrastructure to Support a Digital Society (CEIDS). The study involved interviews with what the study authors noted was a "statisti-

cally representative sample" of 985 firms in three sectors of the US economy that represent 40 % of the U.S. gross domestic product – and which shows particular sensitivity to power disturbances, http://www.epri.com/IntelliGrid.

REFERENCES

Alderfer, B., Eldridge, M. and Starrs, T.: 2000, "Making Connections: Case Studies of Interconnection Barriers and their Impact on Distributed Power Projects," National Renewable Energy Laboratory, Golden CO, USA.

Andrews, E.: 2006, "Vague Law and Hard Lobbying Add Up to Billions for Big Oil," The NY Times, 3/27 (A), 1, New York, NY, USA.

Arthur D. Little: 2000, "Preliminary Assessment of Battery Energy Storage and Fuel Dell Systems in Building Publications," *Final Report to National Energy Technology Laboratory*, US DOE, GS-23F-8003H, Acorn Park, Cambridge, MA, USA.

Ayres, R. Leslie W., and Warr, B.: 2003, "Power and Work in the US Economy, 1900–1908", *Energy*, 28(3), 219–297.

Ayres, R. and Warr, B.: 2005, "Accounting for Growth: The Role of Physical Work," *Structural Change & Economic Dynamics*, 17(2), 181–209.

Bailey, O. and Worrell, E.: 2004, "Clean Energy Technologies, A Preliminary Inventory of the Potential for Electricity Generation," Lawrence Berkeley National Laboratory, Berkeley, CA USA.

Brennan, Timothy J., Palmer, Karen L., and Martinez, Salvador: 2002, "Issues in Restructuring the Electricity Industry." *Alternative Currents: Electricity and Public Policy*, Resources for the Future, New York, pp. 1–10.

Bush, George W.: April 27, 2005, Speech to National Small Business Conference, Washington Hilton Hotel, Washington, DC, USA.

Casten, T. and Collins, M.: 2002, "Recycling Energy," [online] http://www.primaryenergy.com, accessed July 16, 2006.

Commonwealth Edison: 2006, *Con Edison 2005 Annual Report Strength*, [online] http://investor.conedison.com/ireye/ir_site.zhtml?ticker=ed&script=700&layout=7, accessed July 23, 2006.

Electric Power Research Institute's Consortium for Electric Infrastructure to Support a Digital Society (CEIDS): [online] http://www.epri.com/IntelliGrid, accessed July 16, 2006.

[EIA] Energy Information Administration: 2005, *Annual Energy Review 2004*, DOE/EIA-0384(2004), Washington, DC (online) http://www.eia.doe.gov/emeu/aer/, accessed June 21, 2006. Tables 1.3, 8.2a, 8.4a, 8.2a, Diagram 1.

Entergy: 2006, *2005 Annual Report Tested*, [online] http://www.entergy.com/content/investor_relations/pdfs/2005ARFINAL.pdf, accessed July 23, 2006.

Hirst, Eric: 2004, *U.S. Transmission Capacity: Present Status and Future Prospects*, Edison Electric Institute, [online] http://www.eei.org/industry_issues/energy_infrastructure/transmission/USTransCapacity10-18-04.pdf, accessed July 23, 2006.

Huntoon, Steve and Metzner, Alexandra: 2003, "The Myth of the Transmission Deficit," *Public Utilities Fortnightly*, 141(20), pp. 28–33.

[IEA] International Energy Agency: 2002, *World Energy Outlook 2002*, Paris, France [online] http://www.iea.org//textbase/nppdf/free/2000/ weo2002.pdf, accessed June 21, 2006.

Kosanovic, D., Ambs, L., and Beebe, C.: 2005, "The Influence of Distributed Energy Resources on the Hourly Clearing Price of Electricity in a Restructured Market," in *2005 ACEEE Summer Study on Energy Efficiency in Industry*, West Point, NY, July 19–22, 2005.

Kosanovic, D. and Beebe, C.: 2005, "System Wide Economic Benefits of Distributed Generation in the New England Energy Market," Center for Energy Efficiency and Renewable Energy, University of Massachusetts, Amherst, MA, USA.

Lowi, T.: 1979, *The End of Liberalism, the Second Republic of the United States*, WW Norton & Company, New York, NY, USA.

National Academy of Engineering: 2006, *Greatest Engineering Achievements of the 20th Century*, 2nd Ed., National Academies, Washington, DC, http://www.greatachievements.org/, accessed July, 2006.

Natu, S.: 2005, "Bagasse Based Cogeneration, India Marching Ahead", *International Sugar Journal*, CVII, p. 416.

North American Electric Reliability Council: 2005, *Long-Term Reliability Assessment: The Reliability of Bulk Electric Systems in North America*, NAERC, Washington, DC, September, 2005.

[PG&E] Pacific Gas and Electric Company: 2006, Revised Cal. P.U.C. Sheet No. 17097-E, Commercial/Industrial/General Schedule E-20-Service to Customers with Maximum Demands of 1,000 kWh or more, Section 13. Contracts b. Long Term Service Agreement Options 3. Cogeneration Deferral Agreement, p. 22.

Primary Energy: 2006, [online] www.primaryenergy.com/facilities/cokenergy.htm, accessed July 16, 2006.

REN21 Renewable Energy Policy Network: 2005, "Renewable 2005 Global Status Report," Worldwatch Institute, Washington, DC, USA.

Shirley, W: 2001, "Distribution System Cost Methodologies for Distributed Generation," *The Regulatory Assistance Project*, Gardiner, Maine, USA.

Sobin, Rodney: forthcoming, "Renewable Energy Systems could never meet growing Electricity Demand in America," in B.K. Sovacool and M.A. Brown (eds) *Energy and American Society: Thirteen Myths*, Springer Press, The Netherlands.

Turbosteam: [online] www.turbosteam.com, accessed July 16, 2006.

Warr, B. and Ayres, R.: forthcoming 2006, "The MEET-REXS model," *Structural Change & Economic Dynamics*.

World Alliance for Decentralized Energy: 2005, [online] www.localpower.org/documents_pub/report_worldsurvey05.pdf, accessed June 21, 2006.

Zerriffi, H.: 2004, "Electric power systems under stress: an evaluation of centralized vs. distributed systems architectures," *Ph.D. Thesis*, Carnegie-Mellon University.

CHAPTER 10

ENERGY MYTH NINE – ENERGY EFFICIENCY IMPROVEMENTS HAVE ALREADY REACHED THEIR POTENTIAL[1]

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10.1. INTRODUCTION

Overall, the United States now uses 47% less energy per unit of economic output than it did 30 years ago, cutting today's energy costs by a billion dollars a day – like a huge universal tax cut that also cuts the federal deficit. Far from dampening global development, lower energy bills accelerate it. And there's plenty more value to capture. The waste heat thrown away by U.S. power stations – a fifth more energy than Japan uses for everything – could be lucratively recovered and reused if "combined-heat-and-power" were encouraged as it is in Europe. Converting coal at the power plant into incandescent light in the room is only 3% efficient. And around 20 huge power plants spew out CO_2 just to run U.S. equipment that is turned off (Lovins, 2005).

Why do such inefficiencies continue? Many economists, policy analysts, and politicians believe that the country has already captured its energy efficiency potential, and that (as a result) not much promise is left. For example, in their comprehensive assessment of 20 years of industrial energy efficiency projects, Anna Shipley and R. Neal Elliot (2006) conclude that "a recurring theme offered by those opposed to the funding of industrial energy efficiency efforts has been that companies have already realized all the cost-effective industrial energy efficiency opportunities that exist." Richard N. Cooper (2005) notes that "there are many attractive ideas out there [for addressing energy challenges]," including energy efficiency practices and small-scale renewable energy systems like wind turbines. "But when one looks quantitatively at the possibilities for mobilizing them, it is clear that many can play only a niche role" (p. 271). Paul Joskow (1995) argues that "estimates of un-tapped economical energy-efficiency opportunities...are nothing more than fantasy" (p. 531).

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 239–263

Coupled with this notion is the belief that markets will automatically work things out on their own, and that government supported energy efficiency measures are no longer needed. Ronald J. Sutherland and Jerry Taylor (2002) remark that "the market does not fail to deliver to energy supply, energy efficiency, or energy security . . . . Private markets automatically perform cost/benefit analyses and ensure that long-run benefits to consumers are maximized" (pp. 1–3). The Cato Institute concludes that "experience has shown that the invisible hand of the marketplace is far superior in providing for efficient energy use and conservation than is the dead hand of government planners" (Taylor, 1993, p. 1). Ken Gillan (1978) notes that even at the height of the energy crisis of the 1970s, many regulators believed that "if the economic situation really justifies conservation, private companies would already be pursuing research and development in that area, for they would see that conservation technologies are marketable" (pp. 115–116). And two influential articles in *Energy Policy* conclude that "conservation is. . .the inevitable result of economic and technical development" and that "few additional incentives are needed to sell energy-efficient appliances or automobiles because the rewards are real and automatic" (Greenhalgh, 1990; Sioshansi, 1994).

If energy efficiency has so much potential, why hasn't it already been done? Well, it has: the United States, for example, now uses less than half the oil and gas it used in 1975 to produce a dollar of GDP. But why hasn't even more been done? Why hasn't *everything* worthwhile already been done? Naïve economic models assume free markets (even in non-market societies) so perfect that any cost-effective efficiency investments must already have been made, so making more must require higher prices – hence the gloom-and-doom predictions of economic hardship. More careful models, and the experience of every empirical practitioner of energy efficiency, show otherwise. (If markets were really so perfect, all possible innovation would already have occurred, all business opportunities would have been captured, all rents arbitraged out, nobody could make an interesting amount of money, and life would be very dull.)

Interpreting complex human behavior only as a response to price gives a cramped and misleading picture of reality. Price is indeed important and should be correct, but the ability to respond to price matters much more; help, skill, and attention can substitute for high prices. During 1991–1996, people saved peak electric load 12 times faster and electric energy 3,640 times faster in Seattle than in Chicago despite paying half the price per kWh, because the utility promoted savings in Seattle but discouraged them in Chicago. Price is only one way of getting people's attention: amidst record-low and falling energy prices, U.S. energy intensity fell by nearly 3% a year in 1996–2001, almost as fast as the 3.4% a year achieved in 1979–86 with record-high and rising energy prices. (Incidentally, in 2005, U.S. energy use dropped slightly because intensity fell a bit more than GDP grew.) High energy prices aren't necessary for very efficient use of energy (which yields rich returns even at low prices), nor are they sufficient: DuPont's European chemical plants were no more energy-efficient than its U.S. ones despite long having paid twice the energy price, because all the plants were similarly designed. Such basic departures from glib slogans warn us to take economics seriously but not literally.

A key obstacle is that almost everyone underestimates how much energy can be saved. Moreover, saved energy is invisible: it's not itemized in line-item savings off your energy bills. Energy-efficient technologies often look and feel just like inefficient ones, so they're invisible too. Energy savings are as decentralized as energy uses, in millions of small pieces rather than concentrated in gigantic chunks that attract ribbon-cutters and rent-seekers to energy-supplying facilities. Energy efficiency has weak and scattered constituencies. Most energy users take a very short view, discounting future savings ten times faster than financiers discount revenues from selling energy. Most users have little time, attention, or interest to learn about modern efficiency technologies, which evolve so quickly that even experts are outdated. Specific obstacles inhibit using energy in a way that saves money: split incentives between landlords and tenants or builders and buyers, perverse incentives that reward the opposite of what we want, quirks of information flow and organizational behavior, and scores more. In all, some 60–80 market failures, each convertible to a business opportunity, have been catalogued from extensive field experience (Lovins and Lovins, 1997, pp. 11–20). Each of these barriers can be busted, each stumbling-block turned into a stepping-stone, but this requires careful attention, relentless patience, and someone's actually choosing to deal with it. The theoretical claim that market actors automagically vault all obstacles and capture all efficiency opportunities is like the old joke asking how many economists it takes to screw in a light bulb: "None: the free market will take care of it." But someone must actually climb up the ladder and do it!

Thus, 30 years of experience has revealed that efficiency faces numerous obstacles, leaving most of it not yet bought. But efficiency's obstacles are being overcome sufficiently to have sustained an unprecedented 1.5%/y average decline in U.S. electric intensity since 1996, even though electricity is the form of energy most heavily subsidized and most prone to split incentives, is seldom priced on the margin, and is sold by distributors which in 48 states are rewarded for selling more kWh and penalized for selling fewer kWh. (The overall U.S. rate of decrease in primary energy intensity was 2.3%/y during 1996–2004, most of it believed to be due to more efficient use.) Such firms as DuPont, IBM, and STMicroelectronics routinely cut their energy intensity by 6%/y, and word of the resulting juicy profits is spreading.

Indeed, a closer examination suggests that the potential for energy efficiency is actually growing because of the following four factors: breakthroughs in energy-saving equipment and in integrative design, better marketing, and advances in transportation.

10.2. BREAKTHROUGHS IN ENERGY-EFFICIENT EQUIPMENT

The cost of saving energy is falling rapidly, and its decline is accelerating. High-quality adjustable-speed electronic motor drives, once exotic and costly, are now mass-produced in Asia so cheaply that they're given away by electrical contractors who'd otherwise pay more for required protective and soft-start circuits. Quintupled-efficiency compact fluorescent lamps sell for a fifth to a tenth of their 1983 price, now that a billion are made yearly. Real prices have fallen 10-fold in 15 years for electronic lighting ballasts; by 5-fold in 5 years for clear but heat-reflecting window coatings. Indeed, for many kinds of equipment in competitive markets – motors up to at least 225 kW, industrial pumps, common rooftop chillers, televisions, even home refrigerators – careful shopping can make very efficient models cost no more than inefficient ones. Few economists believe this, but it's empirically true. "In God we trust" all others bring data.

Just using everywhere the technologies now used somewhere can save most of the heat and power we use. Since the 1980s, a huge literature has proven that fully applying the best efficiency techniques of the mid-1980s could save half to three-quarters of U.S. electricity, more cheaply than producing it in existing thermal power stations (Fickett et al., 1990). Similar studies found a similarly cheap technical potential to save three-fourths of Danish buildings' or half of all Swedish electricity, or fourth-fifths of German homes' electricity.

Low-hanging fruit keeps mushing up around the ankles. Most big buildings use three times the electricity they should to deliver each unit of air conditioning, and several times the air conditioning they'd need if their shells, lights, and office equipment were properly efficient. In the world's highest-tech industry, chip fabs routinely make chilled water and clean air with twice the energy they should. In another industry shaped by cutthroat cost competition, even the newest oil refineries run most of their pumps against partly closed throttling valves instead of using adjustable-speed motor drives, are controlled by what's happened rather than what's about to happen, and keep boiling and recondensing products well after they're finished, reboiling the average product molecule a couple of dozen times. (When the roast is done, take it out of the oven.)

Meanwhile, the "negawatt tree" keeps raining down even more fruit on our heads. Conventional improvements – more efficient boilers, furnaces, heat recovery, chillers, drivesystems, pumps, fans, production equipment, controls, etc. – are just the tip of a vast iceberg of hidden savings (Lovins, 1996). Some come from clever new gadgets, like featherlight "aerogel" transparent insulation, or aerosolized chewing-gum that finds and plugs duct leaks, or advanced software-based motors and innovative sensors. Some are very old practices, like cogenerating heat and power, getting 2–3 times more useful work from each unit of fuel bought, burned, and emitted as CO_2. But whole new categories of savings are emerging from production and business innovations.

Making things that last longer, use materials more sparingly, and are designed for repair, reuse, remanufacture, and recycling can save most of the energy now needed to make and assemble materials – industry's core task. Microfluidics can eliminate much of the chemical-industry capacity devoted to separating desired from undesired products, by controlling reaction conditions so precisely, in millimeter-scale channels, that only desired products are made. Green chemistry can turn waste (products nobody wants) into profits. Lean production can eliminate enormous materials wastage. And that doesn't even count the emerging revolutions in biomimetics and perhaps in some aspects of nanotechnology and biotechnology.

Opportunities also abound not just in technology but also in business models: the "solutions economy" described in *Lean Thinking* by Jim Womack and Dan Jones (1997), and in our *Natural Capitalism* (Hawken et al., 1999), can yield more and better services from less stuff by rewarding both provider and customer for doing more and better with less for longer.

All these potentials, and more, don't add; they multiply. Even the most advanced industries are barely scratching the surface of how much energy efficiency is available and worth buying. Potential savings aren't limitless, but they're nearly so for the next century-plus. Even the most energy-efficient countries, like Japan, aren't yet a tenth as efficient as the laws of physics permit (a leading Japanese engineer believes, plausibly, that tripling Japan's energy efficiency would be profitable today), and those physical laws can often be finessed by redefining the task – even in as simple a way as illuminating an office by opening the curtains and turning off the lights.

10.3. BREAKTHROUGHS IN INTEGRATIVE DESIGN

While energy efficiency is becoming rapidly cheaper as better *technologies* are produced and adopted at higher volumes, an even greater design revolution is emerging in *design*, in how those technologies are combined and applied: optimizing whole systems for multiple benefits, not isolated components for single benefits.

For instance, how much thermal insulation should your house contain in a cold climate? Most engineers suggest just the amount that repays its cost over time from lower heating bills. But this is methodologically wrong, because it omits the capital cost of the heating system. In a climate that can dip below – 40 °C, my house 2,200 meters up in the Rocky Mountains has no conventional heating system. Instead, its superinsulation, superwindows (whose heat-reflecting films and krypton filling block heat loss as well as 8–14 sheets of glass), and ventilation heat recovery cut heat losses to within $\sim 1\%$ of the free heat gains from sunlight, people, lights, and appliances. (The last $\sim 1\%$ can come from a 50-watt dog, adjustable to 100 W by throwing a ball, or by occasionally running a small woodstove on the coldest nights; one must burn the energy studies somehow.) These features that eliminated the heating system cost less to buy and install than a heating system – furnace, ducts, fans, pipes, pumps, wires, control systems, and fuel-supply equipment. That saved construction cost, plus an extra $16/m^2 in 1984 dollars, was then reinvested to save 90% of the electricity (yielding a $5-a-month electric bill before solar power production), 99% of the water-heating energy, and half the water. Together, these efficiency investments repaid their cost in 10 months with 1983 technologies; today's technologies are better and cheaper.

Likewise in 1994, Pacific Gas & Electric Company's (PG&E) "ACT^2" experiment proved in seven new and old buildings that big savings could generally cost less than small savings (PG&E, 2004). For example, an ordinary-looking new tract house in a 45 °C climate was designed to save 82% of the energy allowed by the strictest U.S. building code. If widely adopted, that design would cost ~ $1,800 less than normal to build and ~ $1,600 less over time to maintain, because it had no heating or cooling equipment. A similar design later proved comfortable at no extra cost in a 46 °C climate. In steamy Bangkok, a 350-m^2 house provided normal comfort, at no extra cost, with a tenth the normal air-conditioning energy. This also works in big buildings and even in fixing up old ones: a design for renovating a 19,000-m^2 curtainwall office building (all glass and no windows) near Chicago, coordinated with replacement of glazings whose seals were failing, could save 75% of the energy with better comfort and no greater cost.

Such astonishing results reveal a flaw in the economic theory of diminishing returns. To be sure, adding far more insulation to my house did initially cost more and save ever less for each increment, because that's how insulation works. But when insulation displaced the entire heating system, its avoided capital cost could be subtracted, yielding a ~ 99% heat saving that cost less than small or no savings. Why get there "the long way around," following the curve, when you can "tunnel through the cost barrier" straight to that goal?

In a striking industrial example, redesigning a heat-transfer "runaround loop" cut pumping energy by 92%, with lower capital cost and better performance, using no new technologies but two changes in design mentality. The first was to use big pipes and small pumps rather than small pipes and big pumps. The friction in a pipe falls as nearly the fifth power of its diameter. Most engineers make the pipe just fat enough to repay its greater cost from saved pumping energy over the years. But this omits the capital cost of the pump, motor, inverter, and electricals that must be big enough to overcome the friction. That equipment's size, hence (roughly) its capital cost, falls as about the fifth power of pipe diameter, while the pipe's cost rises as only about the second power of diameter. Thus optimizing the pipe as a component, and for just one benefit (saved pumping energy), "pessimizes" the system! Optimizing the whole system together, and for two benefits (saving energy and capital), yields fat pipes, tiny pumping equipment, slightly lower total capital cost, and 12 times less pumping energy.

The second design innovation was to lay out the pipes first, then the equipment. Normal practice is the opposite. The equipment is scattered, interspersed with other objects, facing the wrong way, and at the wrong height, so the connecting pipes' circuitous paths cause 3–6 times more friction. The pipefitters rejoice: they're paid by the hour, mark up the extra pipes and fittings, and don't pay for the bigger equipment and electric bills. But the owner would be richer with short, fat, straight pipes than skinny, long, crooked pipes.

Together, then, these design changes cut measured pumping power by 92%, reduced construction cost, and saved 70 kW of heat loss with a 2-month payback (because it's easier to insulate short, straight pipes). But in hindsight, another roughly 4-fold saving, raising total savings to ~ 98%, could have been achieved at even lower cost by properly counting seven additional benefits: less space; less weight; less noise; easier maintenance access; lower maintenance needs; higher reliability; and longer life by eliminating erodable pipe elbows.

Other recent examples from my team's design practice include an 89% energy savings in a data center with lower capital cost and better uptime; ~ 75% in a new chemical plant with ~10% lower construction time and cost; ~ 70–90% in a new supermarket at probably lower cost; 20% (more next time) in a new chip fab at 30% lower capital cost; over 50% in a giant hydrocarbon plant with ~ 20% lower capital cost; and ~ 50% in a luxury yacht with lower capital cost. Retrofit designs paying back in a few years typically save 40 + % of the energy in major facilities ranging from a very efficient oil refinery to huge mines. In a design for an office air-conditioning retrofit, even 97% energy savings appeared worthwhile. And in every case, non-energy performance attributes would improve. My team has lately achieved such results in redesigning nearly $30 billion worth of actual facilities in 28 sectors. If markets were as perfect as the theorists quoted above suppose, no such opportunities could be found; yet practitioners are continuously immersed in them, and are intimately acquainted with the market failures whose reality the theorists deny. This divergence of world-view seems to me an empirical question, and I prefer actual experience to theoretical predictions.

"Tunneling through the cost barrier" to make very large energy savings cost less than small or no savings – expanding, not diminishing, returns – isn't rocket science; it's good Victorian integrative engineering rediscovered, correcting deficiencies in engineering practice, pedagogy, and reward systems (most designers are paid for what they spend, not for what they save). I hope soon to help a "Factor Ten Engineering" (10 × E) team of practitioners write a casebook of high-brain-Velcro examples of whole-system design, as a fulcrum to leverage the nonviolent overthrow of bad engineering and "infectious repetitis."

10.4. BREAKTHROUGHS IN MARKETING ENERGY EFFICIENCY

Most utilities' historic efforts to market "negawatts" provided just information, or information and financing, or (later) rebates for buying efficient equipment. But even more powerful methods invented in the 1980s and 1990s are now starting to be applied to make markets *in* negawatts, maximizing not just participants and savings but also competition in driving savings and their quality up and their cost down.

Another strong selling point for efficiency these days is that it helps to protect the Earth's climate. Best of all, this is not costly but profitable, because efficiency costs less than the energy it saves. Now that most people realize the climate is at risk because of human burning of fossil fuels, the next shoe to drop will be the widespread realization that (as every practitioner proves daily) those concerned about climate protection's costs, burdens, and sacrifices suffer from a sign error: actually they should be talking about profits, jobs, and competitive advantage (Lovins, 2005).

Moreover, past energy efficiency efforts have focused largely on how much money the customer can save by making an investment, and how quickly that investment is repaid from reduced energy bills. Now we can offer typical industrial and commercial customers even larger savings with typically *lower* capital costs for 40–90% savings in new installations, and several-year paybacks on 30–60% savings in retrofits. But for customers not interested in energy, we needn't even mention saved costs, but rather can speak to their concerns in their language. We can focus not on what we care about (energy) but on what the customer cares about: 6–16% higher labor productivity in efficient offices (workers can see what they're doing, hear themselves think, feel more comfortable, and breathe cleaner air, so they do more and better work – worth an order of magnitude more than the entire energy bill), better merchandising and food safety in efficient supermarkets, 40% higher retail sales pressure in well-daylit shops, 20–26% faster learning in well-daylit classrooms, and even better crash safety in efficient cars.

10.5. BREAKTHROUGHS IN TRANSPORTATION

The same integrative design principles apply to cars, trucks, and planes, and indeed to all modes of transportation, which collectively use $\sim 70\%$ of U.S. oil. My team's 2004 independent analysis *Winning the Oil Endgame*, cosponsored by the Pentagon, found that artfully combining modern lightweight materials, aerodynamics, and propulsion innovations could cut all these vehicles' oil use by two-thirds without compromising comfort, safety, or performance (Lovins et al., 2004). That would reverse growing U.S. oil imports. Now add other savings and alternative supplies, and the combined portfolio phases out oil use altogether in the 2040s while revitalizing the economy.

Tripled-efficiency vehicles' extra cost, if any, would pay back in a few years. Indeed, current technology can save 20% of plane energy (as in Boeing's *787*) and 25% of heavy-truck energy (as suppliers recently told a major customer) at zero additional cost. The sorts of economic theorists who lie awake nights wondering whether what works in practice can possibly work in theory assume tradeoffs – e.g., that efficient cars must be small, sluggish, unsafe, costly, or ugly. But in fact, just as consumer electronics routinely become smaller, better, faster, and cheaper, so well-designed energy savings can yield a leapfrog product that sells because it's better, not because it's efficient.

As with insulation, dis-integrated and incremental technologies can save ever less and cost ever more – diminishing returns. The breakthrough to expanding returns comes from whole-system redesign. That's clearest in cars and light trucks – the "light-duty vehicles" that use 42% of U.S. oil and account for 58% of its projected growth to 2025. After 120 years of engineering effort, the modern car remains astonishingly inefficient because of its basic physics. Only 13% of the car's fuel energy even reaches the wheels – the other 87% is lost en route – and of that 13%, over half heats the tires, road, and air. Just 6% of the fuel energy accelerates the car and then heats the brakes when you stop. Since 95% of the accelerated mass is the car, not the driver, less than 1% of the fuel ends up moving the driver. No wonder today's car – the highest expression of the Iron Age – burns each day 100 times its weight in ancient plants in the form of gasoline (Lovins et al., 2004).

But there's a solution (Lovins and Cramer, 2004; Lovins et al., 2004). Three-fourths of the car's fuel use is caused by its weight, and every unit of energy saved at the wheels by reducing weight (or drag) will save an additional seven units of energy now lost en route to the wheels. Fortunately, modern light-but-strong materials – light metals, special new steels, or advanced polymer composites – can slash the car's weight without compromising safety. For example, carbon-fiber composites can absorb 6–12 times as much energy per kilogram as steel, and do so more smoothly, more than offsetting the composite car's weight disadvantage if it hits a steel vehicle twice its weight. With such novel materials, cars can be big (comfortable and protective) but not heavy (hostile and inefficient), saving both oil and lives. You don't need weight for strength; if you did, your bicycle helmet would be made of steel, not carbon fiber.

New manufacturing techniques can make advanced materials affordable. Some carbon-composite processes (www.fiberforge.com) now show promise of competitive cost per car at automotive volumes, meeting all requirements without compromise and with valuable advantages: no fatigue or corrosion, color-in-the-mold (no paint), and bouncing undamaged off a low-speed collision. Such materials' modest extra cost per car can be offset by simpler automaking (the assembly plant becomes two-thirds smaller and two-fifths less capital-intensive) and by the two-thirds-smaller propulsion system. Thus the doubled efficiency of modern hybrid-electric cars can be nearly redoubled at roughly zero extra cost (Lovins et al., 2004).

10.6. ENERGY EFFICIENCY HAS EVEN GREATER POTENTIAL WHEN COMBINED WITH RENEWABLES

Integrating efficient use with renewable supply not only lets previously modest sources fill a larger fraction of the remaining need, but also often makes renewable supplies cheaper and technically more attractive. For example, 1.25 hectares of solar cells added to the roof of a California prison was combined with efficiency and demand response (using power less at costly and more at cheap periods), so at peak periods, the maximum solar output could be mainly sold back to the grid at the best price. This bundling yielded customer benefits 3.8 times cost including state subsidies or 1.7 times cost when state subsidies are excluded. Decentralized generators cheaper than PVs (as almost any kind is) would be even more profitable.

Roughly one-seventh of the world's total primary energy is renewable, half noncommercial biofuels. Most of the rest is large-scale hydroelectric power, mostly overbuilt. But in the past decade, an increasing array of other renewable sources has begun to hit its stride despite centuries or millennia of short-sighted interruptions and decades of recent policy obstructions and lopsided subsidies favoring their mature competitors. Europe plans to get 22% of its power and 12% of its total energy from renewables by 2010, then much more. Denmark already gets 20% of its electricity from wind, Germany 10% (expecting at least 20% by 2020). Germany and Spain are each adding over 2 GW (billion watts) of windpower each year; the global windpower industry, 8; the $38-billion-a-year global renewable power industry, at least 12; all micropower (decentralized renewables plus combined-heat-and-power), 29 (Johansson et al., 1993; Goldemberg, 2001; Sørensen, 2003; www.rmi.org/sitepages/pid171.php#E05-04). In contrast, nuclear power's worldwide additions through the 1990s averaged only 3.2 GW, despite a head-start of a half-century and a trillion dollars just in U.S. subsidies. In 2004, 1.3 GW of global nuclear capacity started construction (barely more than the world's 1.15 GW of solar cell production), 4.8 GW was completed, and 1.4 GW was permanently shut down (Schneider and Froggatt, 2004). Nuclear orders remain stagnant, yet windpower is doubling every 3 years, solar cells every 2 years. In 2005, micropower provided 32% of the world's addition of electrical generation – four times nuclear power's 8% – and added 8–11 times as much capacity. Micropower provided in 2005 from a sixth to more than half of all electricity in a dozen industrial countries, and a sixth of the world's total. How bizarre that many still describe it as slow, small, futuristic, worthwhile, but unlikely to amount to much!

Even at very large scale for a diversified renewable portfolio, land-use concerns are unfounded. For example, a rather inefficient PV array covering half of a sunny area 100 × 100 miles could meet all annual U.S. electricity needs. Of course, one wouldn't do it that way; rather, one would use building-integrated and rooftop-retrofitted PVs, and build PVs into parking-lot shades, alongside highways, etc., to avoid marginal land-use and put the power near the load. Specious claims persist comparing (say) the footprint of a nuclear reactor or power station with the [generally miscalculated] land area of which some fraction – from about half for PVs to a few percent for wind turbines – is physically occupied by renewable energy and infrastructure. But ever since the International Institute for Applied Systems Analysis's *Energy in a Finite World*, it's been well known that properly including the relevant fuel cycles, land intensity is quite similar for solar, coal, and nuclear power (Haefele, 1981). An update might even show a modest land advantage to solar.

A sizeable literature shows that old canards about poor net energy yield from wind and PV technologies are invalid; they generally use very old (or originally grossly erroneous) data on materials intensity. Even some more careful recent papers, such as Professor Per Peterson's, show materials intensities for windpower far above those found by a detailed lifecycle assessment based on actual projects (Peterson, 2001; www.windpower.org/composite-515.htm). Interestingly, it's long been known that a gram of silicon in solar cells will produce more lifetime electricity than a gram of fissionable material in a nuclear reactor – because unlike fission, solar-electric conversion consumes nothing.

Renewables have a very large potential on a global scale. Even under restrictive solar power assumptions, the International Energy Agency's *World Energy Outlook* (2004, pp. 229–232) foresees a potential of $\sim$ 30,000 TWh/y in 2030 – roughly

2030 world electricity demand. Most importantly, a cost-effective combination of efficient use with decentralized (or even just decentralized renewable) supply is ample to achieve climate-stabilization and global development goals, even using technologies quite inferior to today's.

Predicted problems with variable renewables, like solar and windpower, haven't materialized and continue to recede into theoretical haze (www.ukerc.ac.uk/component/option,com_docman/task,doc_download/gid,550/). Danish utility Elkraft System considers 50% windpower by 2025 (the wind industry's goal) technically and economically feasible even though the Danish grid is small. Even in areas of Denmark, Spain, and Germany that get all their power (or more) from wind on some days, intermittence is being gracefully handled in four melded ways: diversifying locations (the wind always blows somewhere, so a few hundred km difference greatly increases reliability), diversifying technologies (conditions bad for wind are usually good for solar and vice versa), integrating with existing hydropower and demand response, and predicting wind patterns just as utilities already predict electricity demand and rainfall. Actually, the intermittence of large thermal power plants is a bigger and costlier problem that utilities have already had to invest billions of dollars to manage through reserve margins and extra transmission links. For example, a typical U.S. nuclear power plant, even if it runs flawlessly, still shuts down completely for refueling for an average of 37 days every 17 months. The 2003 northeast blackout stopped 20 U.S. and Canadian reactors instantly and without warning. No windfarm is so undependable.

Intermittent generators don't need significant backup or storage, even if tripled in storage-poor Germany; they're unreliable to a different degree and for different reasons than coal or nuclear power plants, but in smaller pieces and in more tractable and predictable ways. They're also far more resilient against and less attractive to terrorists. We can be far more confident that the sun will rise and the wind will blow tomorrow than that someone won't blow up the Saudi oil terminals, a key American pipeline, a nuclear plant, or a critical coal railway line tomorrow.

Windpower is the greatest success story of the $38-billion-dollar-a-year global distributed-renewable electricity industry, led by such giants as General Electric and Mitsubishi. Mass production and improved engineering have made modern wind turbines big (2–3 MW each), extremely reliable, environmentally quite benign (save for those who prefer the esthetics of a comparable number of transmission pylons bringing power from a remote central station), quickly installable, very efficient, and highly competitive. In 2003, U.S. wind energy sold for an unsubsidized $0.045/kWh – cheaper than from a new coal or nuclear plant. By 2005, the latest 2.7 GW of U.S. windfarms had shown an average cost (including an $0.008/kWh levelized Production Tax Credit) of $0.037/kWh, and the cheapest installations cost only $0.015/kWh. The cost-effective wind resource is extremely large – big enough to meet all U.S. annual needs not just for electricity but for total energy. All U.S. electricity could be cost-effectively supplied by windfarms occupying a few percent of available windy land in just a few of the windiest states. Windpower alone is now known to be cost-effectively able to provide twice U.S. or Chinese electricity requirements on those countries' available windy land, or nine times the world's (including offshore areas to a sea depth of 50 m).

A half-dozen recent technical breakthroughs promise dramatic further reductions in the cost of solar cells (photovoltaics or PVs) – already the cheapest way to get electricity to most of the two billion people who have none. In the next generation, this could well become true for the rest of us. Indeed, it may already be true, even with no further technological progress or production scale-up, simply because of an analytic discovery. *Small Is Profitable* (Lovins et al., 2004, an *Economist* book of the year) found in 2002 that decentralized ways to make electricity are typically ~ 10 times more valuable than had been thought, thanks to 207 previously uncounted "distributed benefits" from electrical engineering and financial economics. For example, PVs supporting a typical electrical substation on hot afternoons (when demand surges) are worth 2.7 times more when one properly counts the reduction in financial risk, because a fast, small, granular investment is less risky than a slow, big, lumpy one. Windpower is worth ~ 1–2 cents/kWh more than expected versus a gas-fired combined-cycle plant, because gas prices are three times as volatile as the stock market – a costly financial risk – whereas fuelless windpower has no price volatility. As investors start to quantify these new forms of value, renewables will win more often.

10.7. THE ECONOMIC, SOCIAL, AND ENVIRONMENTAL BENEFITS OF ENERGY EFFICIENCY

Some people confuse energy efficiency – doing more with less through smarter technologies – with what others pejoratively call "energy conservation" – doing less, worse, or without – and hence reject elegant frugality for fear of involuntary penury. Yet energy efficiency is not a hairshirt or a moralistic bludgeon; properly done, it raises our living standards. It also provides one of the *cheapest* ways of delivering electrical services, with an average cost ranging from less than one to a few cents per saved kWh.

Nearly all U.S. peak power is now made very inefficiently by gas-fired simple-cycle combustion turbines. Saving 1% of U.S. electricity, including peak hours, thus saves 2% of all U.S. natural gas and cuts its price by 3–4%. Simple, well-proven electric efficiency and demand response programs could quickly cut $50+ billion a year off U.S. gas and power bills. Across all sectors, efficiency can save half of U.S. natural gas, about 6–8 times cheaper than buying gas today (Lovins et al., 2004).

Saving energy is often not just cheaper but also faster than any other option. During 1973–86, the U.S. doubled its new-car efficiency, and during 1977–1985, grew its GDP by 27% but slashed its oil use by 17%, its oil imports by 50%, and its oil imports from the Persian Gulf by 87%. This helped cut OPEC's exports by 48%, breaking that cartel's pricing power for a decade. The U.S. had more market power than OPEC, but on the demand side: America is the Saudi Arabia of negabarrels, able to save oil faster than OPEC could conveniently sell less oil.

Saving electricity is even more lucrative and can go even faster. During 1983–1985, ten million people served by Southern California Edison Company cut the decade-ahead forecast of peak electric load by 8½% percent per year, at ~ 1% of the cost of adding more supply. In 1990, New England Electric System enlisted 90% of a small-business retrofit pilot market in 2 months. Also in 1990, PG&E marketers signed up a fourth of new commercial buildings for design improvements ... and then in 1991, raised the target and captured it all in the first nine days of January. New methods, deploying today's better and cheaper technologies in new integrative designs, can drive savings even faster, wider, and deeper.

Decentralized power generation, too, can be added quickly. During 1979–1985, more new U.S. generating capacity was ordered from small hydro plants and windpower than from coal and nuclear plants, not counting their cancellations (over 100 GW), even though nuclear got 24 times more subsidy than non-hydro renewables per unit of energy produced. During 1981–1984, when federal policy strongly favored new coal and nuclear plants, their U.S. orders and firm letters of intent minus cancellations totaled –65 net GW, while cogeneration (a fifth of it renewable) added 25 GW; small hydro, windpower, etc. over 20 GW; and efficiency and load management, even more. These smaller, faster, disfavored, but cheaper options cut investors' financial risk and minimized regret. Today's far more mature decentralized power sources are beating nuclear power and other central stations even more decisively in the marketplace.

The economics of climate protection must properly count the benefits of abating multiple greenhouse gases at a time. Cogenerating with landfill or coal-bed methane that would otherwise leak into the air earns carbon credits at power plant and boiler, a methane credit, and a reduced electricity bill. Advanced refrigerator insulation avoids burning enough to fill up the refrigerator every year, but also displaces climate- or ozone-damaging refrigerants and insulation-blowing gases. Recycling paper reduces landfill methane, papermaking and transportation fuel, and soil carbon lost by simplifying mature forest ecosystems. Composting reduces landfill methane, food transportation fuel (the average molecule of U.S. food is shipped ~ 2,000 km), and refrigeration; displaces synthetic fertilizer that releases CO_2 when made and N_2O when used; and helps soil hold water, reducing energy-intensive irrigation. Native building materials displace fuel- and transport-intensive manufacture and CO_2-releasing production and curing of Portland cement (the source of 8% of global CO_2). Efficient motor vehicles can profitably and simultaneously save CO_2, CO, O_3, N_2O, NO_x, SO_x, hydrocarbons, and other heat-trapping gases. And negawatts that displace new hydroelectric dams not only save fuel at negative cost but also keep above- and below-ground biota from becoming CO_2 as impoundment vegetation is cleared and CH_3 as it rots. Other major opportunities for multi-gas abatements are available in farming and forestry, especially in less grain-intensive or wholly grass-based livestock rearing.

The same innovations that reduce carbon emissions from burning fossil fuel will also abate air pollution that harms public health. Substituting efficiency and cost-effective renewables for fossil-fueled power generation can pay for backing out the dirtiest plants and cleaning up the rest. Some of the savings should also reward the utility's customers and shareholders, so all have aligned incentives. Likewise, efficient vehicles' benefits can flow to shareholders and the planet. Sustainable farm, ranch, and forest practices can pay huge dividends – not least, protecting topsoil, genes, water, fuels, farms, farmers, and rural culture. Informal estimates suggest that most, perhaps around 90%, of the problems that the U.S. Environmental Protection Agency deals with could be solved, at negative cost, just by energy efficiency and by sustainable farming and forestry, as byproducts of protecting the climate at a profit.

Similar benefits would flow to national and global security and to equitable global development. Efficiency is available to all, especially in developing countries. They average three times the energy intensity of the U.S., which is about half as efficient as the most efficient countries, which in turn are several- to many-fold less efficient than they should be. Renewable energy is available in diverse forms throughout the world, including where there's no distribution infrastructure, and can often be harnessed with vernacular technology. Sunlight is most abundant where most of the world's poorest people live. In no place between the polar circles is freely delivered renewable energy, capturable with existing technology, inadequate to support a good life cost-effectively and indefinitely – if the energy is used in a way that saves money.

A best-buys-first energy strategy should be far more robust and resilient in the face of surprises and disruption. More efficient, diverse, dispersed, and renewable energy systems are the key to making major interruptions of supply impossible by design, rather than (as now) inevitable by design.

Most importantly, reversing the terrible exponential arithmetic of burning more fossil fuel faster and faster – shrinking the amount of carbon annually released, by making efficiency and substitution for fossil fuels outpace economic growth – makes the "tail" of "global warming commitment" gradually become so slender that its length becomes unimportant. This creates a leisurely period for displacing the remaining fossil-fuel use or for mastering and deploying carbon sequestration. Energy efficiency buys not just saved dollars and avoided pollution but also more time to develop and deploy still better technologies, on both the demand and the supply side, supporting better choices.

These advantages put a premium on buying many short-lead-time, easily deployed efficiency and renewable technologies everywhere, especially in the countries with the greatest institutional capacity or the greatest urge to leapfrog (as China is starting to do). Technologies that deploy like cell phones and personal computers are faster than those that build like cathedrals. Options that can be mass-produced and adopted by millions of customers will save more carbon and money sooner than those that need specialized institutions, arcane skills, and suppression of dissent. Those that fit competitive markets and transparent governmental decisionmaking will have an edge. Those that can survive brutal but technology-neutral competition will ultimately win.

10.8. CASE STUDY: COMPARING ENERGY EFFICIENCY IMPROVEMENTS TO NUCLEAR POWER

Nuclear fission provides a sixth of the world's electricity, about as much as hydropower and other renewables, but that is likely to decline as old plants retire and few get ordered. The United States and Europe have roughly half the world's nuclear capacity, but run fewer nuclear plants today than in 1990, will close some in the next 20 years, and will build very few more in the near-term, because new nuclear plants, of any type and under any system of government, are unfinanceable in the private capital market. They've never been bid into a competitive power auction, are bought only by central planners, and are challenged by global trends toward more competitive markets and transparent governance.

National energy policy currently rests on and reinforces the illusion of a nuclear "revival." Ingenious advocates conjure up a vision of a vibrant nuclear power industry poised for rapid growth, with no serious rivals in sight, and with a supposedly vital role in mitigating the threat of climate change. A credulous press accepts this supposed new reality and creates an echo-box to amplify it. Some politicians and opinion leaders endorse it. Yet industry data reveal the opposite: a once significant but now shrinking industry already fading from the marketplace, overtaken and humbled by swifter rivals. In 2004 alone, Spain and Germany each added as much wind capacity – two billion watts (GW) – as nuclear power is adding worldwide in each year of this decade. Nuclear construction starts may soon be adding less capacity than solar cells. And in the year 2010, nuclear power is projected by the International Atomic Energy Agency to add only a few percent as much net capacity as the decentralized electricity industries project their technologies will add.

That astonishing ratio will increase further, not only because micropower is growing so fast from a base that's already bigger than nuclear power, but also because the aging of nuclear plants is about to send global installed nuclear capacity into a steady decline. Mycle Schneider and Antony Froggatt (2004) have shown that the world's average reactor is 22 years old, as is the average of the 107 units already permanently retired. Their analysis of reactor demographics found that if the reactors now operating run for 40 years (32 under German law), then during the next decade, 80 more will retire than are planned to start up; in the following decade, 197; in the following, 106; and so on until they're all gone around 2050. Even if China built 30 GW of nuclear plants by 2020, it'd replace only a tenth of the overall worldwide retirements. No other nation contemplates anywhere such an ambitious effort, and even China seems unlikely to complete that proposed addition as its power market becomes more competitive and its polity more transparent.

Worldwide, low- and no-carbon decentralized sources of electricity surpassed nuclear power in capacity in 2002 and in annual output in 2006. In 2004, they added 5.9× as much capacity and 2.9× as much annual output as nuclear power added; in 2005, 8× without or 11× with peaking and standby units, and 4×, respectively. (Output lags behind capacity because nuclear plants typically run more hours per year than windpower and solar power – though other renewables, like fossil-fueled cogeneration, have high average capacity factors.) The post-2005 projections shown in Figures 10.1 and 10.2 are those of the respective industries, and are imprecise but qualitatively clear. Large hydro (over 10 MW_e) is not shown in these graphs nor included in this analysis. Two-thirds of the decentralized non-nuclear capacity shown is fossil-fueled co- or trigeneration (making power + heat + cooling); its total appears to be conservatively low (e.g., no steam turbines outside China), and it is ~ 60–70% gas-fired, so its overall carbon intensity is probably less than half that of the separate power stations and boilers (or furnaces) that it has displaced.

Thus the global nuclear enterprise has been eclipsed by its decentralized competitors, even though they receive smaller U.S. federal subsidies per kWh and are often barred from linking fairly with the grid. The runaway nature of the competitors' market victory is evident in Figure 10.3, which shows the global additions of electric generating capacity by year and by technology. Nuclear power's allegedly "small, slow" decentralized low- and no-carbon supply-side competitors are growing far faster, and are taking off rapidly while nuclear additions fade. Note also the light dotted line of nuclear construction starts, a leading indicator. (It stops in 2005 because future plans are uncertain; due to lead times, this won't affect 2010 completions, for which a conservatively high estimate is given; several units are likely to slip into 2011 or beyond.)

Moreover, these striking graphs show only the supply side. Electric end-use efficiency may well have saved even more electricity and carbon. Most countries don't track it, so it can't be rigorously plotted on the same graph, but clearly it's a large and expanding resource. As one rough indication, the 1.98% drop in U.S.

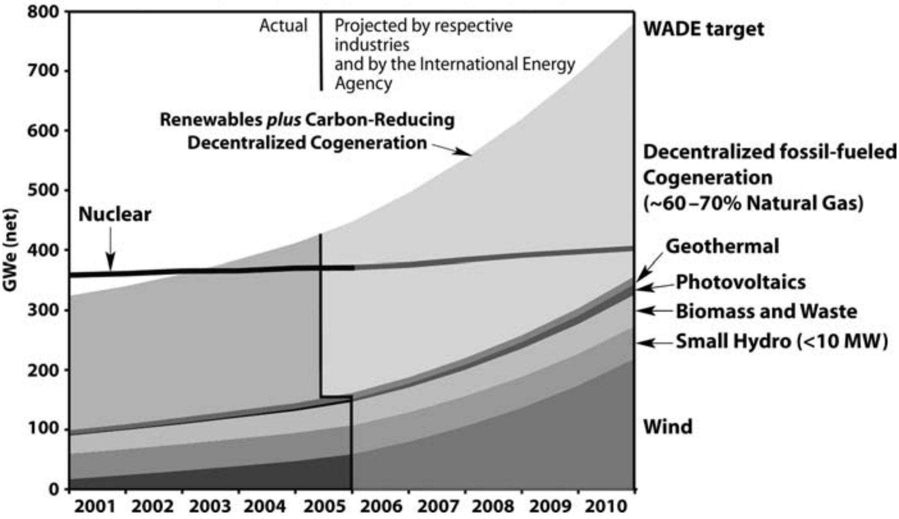


Figure 10.1. Low- or no-carbon worldwide installed electrical generating capacity (except large hydro)

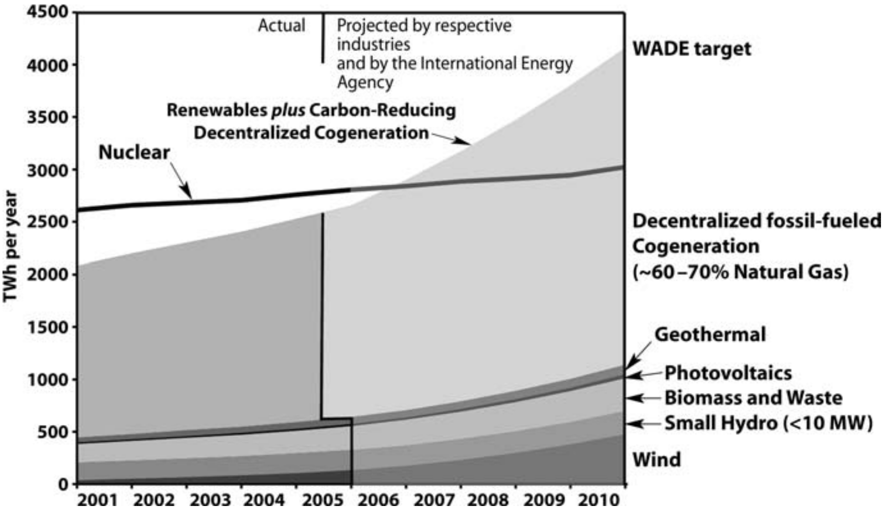
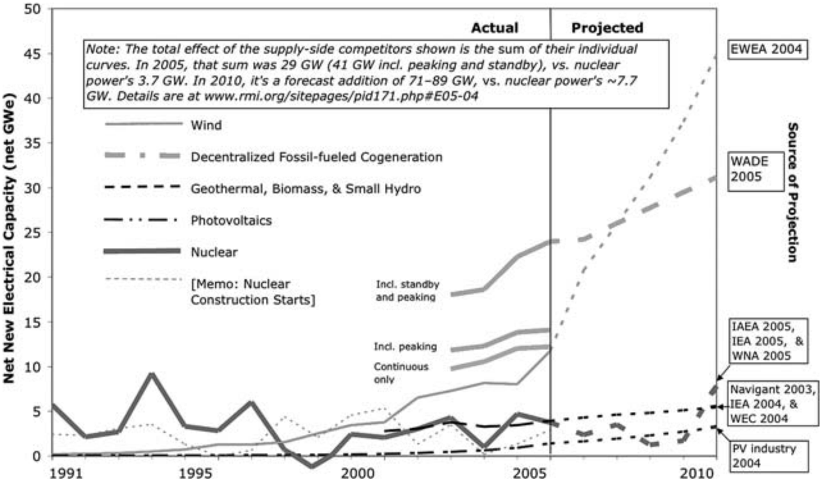


Figure 10.2. Low- or no-carbon worldwide electrical output (except large hydro)

electric intensity in 2003 (whatever its causes) would correspond, at constant load factor, to saving 13.8 GW_p– 6.3× U.S. utilities' declared 2.2 GW_p from demand-side management – and the 2004 intensity drop of 2.30% would have saved > 16 GW_p (plus 1 GW_p/y from utility load management actually exercised). The U.S. uses only one-fourth of the world's electricity, so it's hard to imagine that global savings don't rival or exceed global additions of distributed generating capacity



Note: The total effect of the supply-side competitors shown is the sum of their individual curves. In 2005, that sum was 29 GW (41 GW incl. peaking and standby), vs. nuclear power's 3.7 GW. In 2010, it's a forecast addition of 71–89 GW, vs. nuclear power's ~7.7 GW. Details are at www.rmi.org/sitepages/pid171.php#E05-04

Figure 10.3. Global additions of electrical generating capacity by year and technology: 1990–2005 actual & 2006–2010 projected

(24 GW in 2003, 28 GW in 2004). Thus these total global additions must exceed annual nuclear capacity growth by upwards of 10-fold. Together, then, the low- or no-carbon supply- and demand-side resource deployments actually occurring in the global marketplace are already bigger than nuclear power and are growing an order of magnitude faster – simply because the non-nuclear competitors have lower costs and lower financial risks.

Standard studies compare a new nuclear plant only with a central power plant burning coal or natural gas. They conclude that new nuclear plants' marked disadvantage in total cost might be overcome if their construction became far cheaper, or if construction and operation were even more heavily subsidized, or if carbon were heavily taxed, or if (as nuclear advocates prefer) all of these changes occurred. But those central thermal power plants are all the wrong competitors. None of them can compete with windpower (and some other renewables), let alone with two far cheaper resources: cogeneration of heat and power, and efficient use of electricity. The MIT study (2003), like every other widely quoted study of nuclear economics, simply didn't examine these competitors, on the grounds of insufficient time and funding, and hence could draw no conclusions about them.

New nuclear plants are cheap to run but prohibitively costly to build – uncompetitive with new coal- and gas-fired central power stations. All these central plants are highly uncompetitive with three fatal rivals that most studies ignore: efficient use of electricity ($\sim$ 10–30× cheaper than a new nuclear plant), windpower ($\sim$ 2–3 times cheaper), and gas-fired coproduction of heat and power in factories and buildings ($\sim$ 5–10 times cheaper, net of the heat value). Costing carbon emissions would equally advantage the first two competitors and partially advantage the third. Counting distributed benefits would put the central stations even further out of the money. And these three strong competitors, with more on the way, are all getting better and cheaper far faster than nuclear power is or ever can. New reactor types wouldn't change the basic picture even if they were free, because the non-nuclear parts of the plant still cost too much.

In recent years, most existing U.S. nuclear plants have been better run under more concentrated and skilled ownership. But these organizational gains may not be sustained as the business continues to decline. No vendor has made money selling reactors, few university nuclear engineering departments survive, none can attract top students, and so the unsolved noneconomic problems – weapons proliferation, sabotage and terrorist attack, operational safety, permanent waste disposal, and decommissioning – are ever less likely to get solved.

Costly oil is a poor rationale for reviving nuclear power: less than 3% of U.S. oil makes electricity, and less than 3% of electricity is made from oil (nine-tenths of it the gooey bottom of the barrel). Worldwide, these linkages are only about 7%. Nuclear power for climate protection is also a flawed argument. New nuclear plants cost far more than their no- or low-carbon competitors, so they buy less coal displacement per dollar. For example, since electric efficiency is 10–30 times cheaper than a new nuclear plant per kWh delivered, each dollar spent on nuclear power will buy only about 3–10% as much climate solution as spending the same dollar on efficient use – thus making climate change worse. Indeed, nuclear power's potential market is limited to electricity production, which releases only 40% of the world's CO_2, and nuclear power has dim economic prospects as a source of heat, hydrogen, or mobility fuels. In contrast, efficiency and renewables can cover all applications, sectors, and fuels.

Nuclear advocates riposte that all the alternatives are wonderful and necessary but will never amount to much, individually or collectively, so nuclear is the only option big enough and fast enough to matter. No analysis supports such claims, and they're clearly untrue. On the contrary, competitive bidding, whenever tried, has always blown away central stations. When California created a relatively fair and open market during 1982–1985, private bidders contracted for 23 GW of savings and 13 GW of new generation (mostly renewable). That was just 1 GW shy of 1984 peak demand (37 GW) – yet a further 8 GW of generation was on firm offer, with 9 GW of additional offers arriving every year. This glut caused a failure of nerve, and the bidding was hastily suspended just before it displaced every nuclear and fossil-fueled central plant in California – which could, as we now see in hindsight, have avoided the 2000–2001 California power crisis.

A portfolio of least-cost investments in efficient use and in decentralized generation will beat nuclear power in cost and speed and size by a large and rising margin. This isn't hypothetical; it's what today's market is proving decisively. Indeed, there is good historical reason to believe that nuclear power's perceived problems and actual capital costs tend to increase as it expands. At the height of U.S. nuclear growth, the more coal or (especially) nuclear plants were built or being built, the more their real cost rose. (Later costs closely tracked the coal curve but far overshot the nuclear curve.) Statistical testing strongly suggested an underlying causation that's bad news for nuclear power. It could be even more troublesome at the scale that the nuclear enterprise would need to achieve to make any significant dent in climate change. Dr. Tom Cochran (2005) has estimated that adding 700 nuclear GW_e worldwide – roughly twice today's nuclear capacity – and running it for 2050–2100 would:

- add $\sim 1,200$ nuclear plants (if they lasted 40 years);
- require 15 new enrichment plants (each 8 million SWU/y);
- create 0.97 million tonnes of spent fuel, requiring 14 Yucca Mountains, and containing $\sim$ 1 million kg – hundreds of thousands of bombs' worth – of plutonium...or
- require 50 new reprocessing plants (each 800 TSF/y with a 40-y operating life) to extract that plutonium under, one hopes, stringent international safeguards;
- require $\sim$ $1–2 trillion of investment; and yet
- cut the global average temperature rise by just 0.2 °C.

Similarly daunting numbers were published by RMI researchers Dr. Bill Keepin and Greg Kats (1988). They showed that under the demand-growth assumptions then popular, building a 1-GW reactor every 1–3 days through 2025 couldn't reverse CO_2 growth, so nuclear power "cannot significantly contribute to abating greenhouse warming, except possibly in scenarios of low energy growth for which the problem is already largely ameliorated by efficiency improvement." Since 1988, the economic and logistical logic of non-nuclear investments has only become far more compelling; Dr. Cochran has simply reminded us of the futility of relying on one dominant and slow option rather than on a diverse and well-balanced portfolio of quicker options.

Does this mean that abating climate change (to the major extent it's caused by fossil-fuel CO_2) is hopeless because of the sheer scale of the carbon substitution required? No; rather, it means that:

- much, indeed most, of the carbon displacement should come from end-use efficiency, because that's both profitable – cheaper than the energy it saves – and fast to deploy;
- end-use efficiency should save not just coal but also oil – particularly in transportation, which in the U.S. in 2003 emitted 82% as much CO_2 as all power generation: indeed, since power generation emits only 39% of total U.S. CO_2, an across-the-board energy-efficiency focus addresses 2.5 times as much CO_2 emission as an electricity-only focus;
- supply-side carbon displacements should come from a diverse portfolio of short-lead-time, mass-producible, widely applicable, benign, readily sited resources that can be adopted by many actors without complex institutions or cumbersome procedures; and
- the total portfolio of carbon displacements should be both fast in collective deployment (MW/y – or, more precisely, TWh/y) and effective (carbon displaced per dollar).

This last point highlights perhaps the most troublesome unheralded drawback of nuclear power. Buying a costlier option, like nuclear power, instead of a cheaper one, like the competitors shown in Figure 10.4, displaces less carbon per dollar spent. This opportunity cost is an unavoidable consequence of not following the least-cost investment sequence: the order of economic priority is also the order of environmental priority. For example, based on the indicative costs in Figure 10.4, and neglecting the energy embodied in manufacturing and supporting the technologies (or, equivalently, assuming that they all have similar embodied energy intensity per dollar), we could displace coal-fired electricity's carbon emissions by spending ten cents to deliver roughly:

- 1.0 kWh of nuclear electricity at 2004 subsidy levels and costs, or
- 1.2–1.7 kWh of dispatchable windpower at no to 2004 subsidies and 2004–2012 costs, or
- 0.9–1.7 + kWh of gas-fired industrial cogeneration or ~ 2.2–6.5 + kWh of building-scale cogeneration (both adjusted for their carbon emissions), or
- 2.4–8.9 kWh of waste-heat cogeneration burning no incremental fuel (more if credited for burning less fuel), or
- from several to 10 + kWh of end-use efficiency.

The ratio of net carbon savings per dollar to that of nuclear power – the reciprocal of their relative costs of saved or supplied energy – is their ratio of effectiveness in climate protection per dollar. This comparison reveals that nuclear power saves as

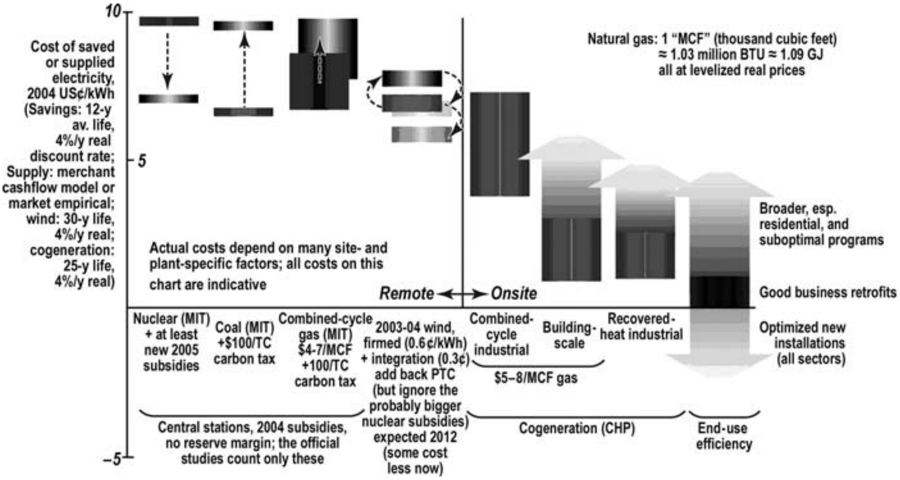


Figure 10.4. Nuclear power's competitors (details in RMI Publ. E05–14 and –15; see Note, p. 262)

little as half as much carbon per dollar as windpower and cogeneration, and from severalfold to at least 10-fold less carbon per dollar than end-use efficiency. Or as Keepin and Kats (1988) arrestingly put it, based on their still-reasonable estimate that efficiency would save ∼ 7× as much carbon per dollar as nuclear power, "every $100 invested in nuclear power would effectively release an additional tonne of carbon into the atmosphere" – so, counting that opportunity cost, "the effective carbon intensity of nuclear power is nearly six times greater than the direct carbon intensity of coal fired power." Whatever the exact ratio, this finding is qualitatively robust even if nuclear power becomes as cheap as its advocates claim it can, but its competitors don't. Recall also that this paper has used assumptions systematically favoring nuclear power, and didn't count nuclear power's 2004 subsidies, which could well be cutting its apparent cost by about half (even more with its new 2005 subsidies).

A popular euphemism holds that we must "keep nuclear energy on the table." What exactly does this mean? Continued massive R&D investments for a "mature" technology that has taken the lion's share of energy R&D for decades (39% in OECD during 1991–2001, and 59% in the United States during 1948–1998)? Ever bigger taxpayer subsidies to divert investment away from the successful competitors? Heroic life-support measures? Where will such efforts stop? We've been trying to make nuclear power cost-effective for a half-century. Are we there yet? When will we be? How will we know? And would nuclear advocates simply agree to de-subsidize the entire energy sector, so all options can compete on a level playing field?

The Energy Policy Act of 2005 is festooned with lavish subsidies and regulatory shortcuts for favored technologies that can't compete unaided. Nuclear expansion, for example, gets ∼ $13 billion in new gifts from the taxpayer: 80% loan guarantees (if appropriated), ~ \$3 billion in R&D, 50% licensing-cost subsidies, \$2 billion of public insurance against any legal or regulatory delays, a 1.8 cents/kWh increase in operating subsidies for the first 8 years and 6 GW (equivalent to a capital subsidy of ~ \$842/kW – roughly two-fifths of likely capital cost), a new \$1.3-billion tax break for decommissioning funds, and liability for mishaps capped at \$10.9 billion (and largely evadable through shell companies). The industry already enjoyed Treasury payments to operators as a penalty for late acceptance of nuclear waste (which there's no place to put nor obvious prospect of one), free offsite security, and almost no substantive public participation in or judicial review of licensing. The total new subsidies approximate the entire capital cost of six big new nuclear plants. Taxpayers have assumed nearly all the costs and risks they didn't already bear; the promoters, who aren't willing to risk any material amount of their own capital (despite ~ \$447 billion of 2003 revenues), will pocket any upside. Yet soon after these new subsidies were signed into law, Standard and Poor's issued two reports saying the credit ratings of the builders wouldn't materially improve, because most of the risks that concern the capital market remained undealt-with. I conclude that the subsidies' effect will be roughly that of defibrillating a corpse: it will twitch, but it won't revive. And that's good for climate protection, because the urgency of the climate problem makes it vital to buy the most solution per dollar and the most solution per year.

A state government committed to market-based, least-cost energy policies could do much to correct the distortions introduced by misguided federal policies. State energy taxes might even be designed to offset federal energy subsidies, technology-by-technology, to create a "subsidy-free zone." This should have a salutary effect on energy cost, security, environmental impacts, and broad economic benefits. Just talking seriously about it and analyzing its consequences could help to focus attention on the differences between current federal energy policy and sound free-market principles. Such a state could become the first jurisdiction in the world to allow all ways to save or produce energy to compete fairly and at honest prices, regardless of which kind they are, what technology they use, how big they are, or who owns them. Who could be against that?

10.9. POLICY RECOMMENDATIONS AND CONCLUSIONS

Energy solutions are hard, requiring millions of smart choices over decades. Climate stability is restored by personal actions – one lamp and motor at a time, one caulk gun and insulation batt at a time, one car choice and factory design at a time. But the climate problem has been caused by millions of choices already made by the same people over decades, driven by bad information, skewed incentives, and dumb policies. Governments should steer, not row, but they should steer in the right direction. Business and civil society can lead in the direction of least economic and political resistance. The best news about climate change is that it's a problem we needn't have, and it's cheaper not to. Because the solution is not costly but profitable, it's gaining speed in the marketplace, led by smart firms seeking shareholder value and spurred by civil society's demands.

The single biggest way the government could help is to get out of the way. It needs to purge the subsidies that hide energy costs in general taxation (which in the United States pays most of the social costs of driving, even though a third of Americans don't drive). Whether through markets or rules, full and fair competition, at honest prices, between all ways of getting around or not needing to would give us still wider choices and better lives. The same is true in all non-transportation uses. If all ways to save or supply energy were allowed and required to compete fairly, much of energy systems' cost and most if not all of their climatic and other environmental harm would disappear. Climate change, conflict, instability, poverty, and (mostly) nuclear proliferation (Lovins, 1980) would be revealed as nasty artifacts of economically inefficient energy policies.

Much systematic barrier-busting is needed too. Few jurisdictions let decentralized power sources "plug and play" on the grid, as modern technical standards permit; many countries don't let private generators sell back power at all. Most of the 31 U.S. states that allow "net metering" (the utility buys your power at the same price it charges you) artificially restrict or distort this competition. And the biggest single obstacle to electric and gas efficiency – easily fixed – is that all but two of the United States, and most other countries, reward their distribution utilities for selling more energy and penalize them for cutting customers' bills.

The main obstacle to energy efficiency in more efficient countries, like Europe and Japan, is the mistaken belief that they're already very efficient. (Everyone has a long way to go.) The main obstacle in developing and formerly centrally planned economies is lack of open markets and institutional capacity – certainly not lack of brains, which are evenly distributed, one per person. Developing countries indeed have the greatest need and incentive to build their infrastructure efficiently the first time; otherwise supply-side investments will rob capital from everything else and stifle development. But conversely, building factories to make superwindows and compact fluorescent lamps needs about a thousand times less capital, and repays it ten times faster, than supplying more electricity to provide the same comfort and light. That $\sim$ 99.97% capital saving can turn the power sector, which now gobbles a fourth of global development capital, into a net exporter of capital to fund other pressing development needs.

Superefficient vehicles are held back by sluggish innovation in much of the ponderous automaking industry, by customers' limited choices and short view of efficiency, and by the unpriced social costs of oil, where gasoline looks cheaper than bottled water. The most powerful policy response is "feebates": charging fees on inefficient new cars, and returning that revenue as rebates to buyers of efficient models. Done separately for each size class, this wouldn't incentivize smaller vehicles, but would expand customers' choices, increase both drivers' and automakers' profits, and signal buyers to make societally efficient choices that count fuel savings over the vehicle's life, not just the first few years. *Winning the Oil Endgame* (Lovins et al., 2004) offers a portfolio of such practical policies – supporting, not distorting, business logic, mainly at a state level – to speed the adoption of advanced-technology cars, trucks, and planes without mandates, taxes, subsidies, or significant national laws.

Today's increasingly competitive, transparent, and globalized economic and political system is eliciting a pattern of energy investment very different than old ones hatched in favoritism, oligopoly, and secrecy. The emerging economic winners will protect climate, create widespread wealth, nurture fairness and openness, support community vitality and personal initiative, and build real security. This market convergence on a common portfolio of profitable choices holds promise for a fairer, richer, and safer world.

NOTE

[1] This chapter was inspired by two shorter articles: A.B. Lovins, "Nuclear power: economics and climate-protection potential," Rocky Mountain Institute, 11 Sept./8 Dec. 2005, accessed June 2006 at www.rmi.org/sitepages/pid171.php#E05-14, summarized in "Mighty Mice," Nucl. Eng. Intl., pp. 44–48, Dec. 2005, www.rmi.org/sitepages/pid171.php#E05-15 and A. B. Lovins, "More Profit With Less Carbon," *Scientific American* (September, 2005), pp. 74–82. For a much greater list of references, please consult these two documents, both available on the Rocky Mountain Institute website, http://www.rmi.org.

REFERENCES

Cochran, Thomas: 2005, "Presentation at the June 22, 2005, Natural Resources Defense Council Board Meeting," Washington, DC, [online] http://www.nrdc.org/nuclear/cochran/cochranpubs.asp, accessed July 2006.

Cooper, Richard N.: 2005, "Comments and Discussion – Sustainable Energy," *Brookings Papers on Economic Activity* **2**, 270–284.

Fickett, A.P., Gellings, C.W., and Lovins, A.B: 1990, "Efficient Use of Electricity," *Scientific American* **263**(3): 64–74.

Gillan, Ken: 1978, "Federal Research Programs for Energy Conservation in Buildings and Communities," in Raymond Burby and A. Fleming Bell (eds) *Energy and the Community*, Ballinger, Cambridge, MA, pp. 115–120.

Goldemberg, J.: 2001, *World Energy Assessment: Energy and the Challenge of Sustainability*, United Nations Development Programme and World Energy Council, New York, NY.

Greenhalgh, Geoffrey: 1990, "Energy Conservation Policies," *Energy Policy*, April, 293–299.

Haefele, W.: 1981, *Energy in a Finite World*, Ballinger, Cambridge, MA.

Hawken, P.G., Lovins, A.B., and Lovins, L.H.: 1999, *Natural Capitalism: Creating the Next Industrial Revolution*, Back Bay Books, New York.

[IEA] International Energy Agency: 2004, *World Energy Outlook*, IEA Publishing, Paris.

Johansson, T.B, Kelly, H., Reddy, A.K.N., and Williams, R.H. (eds): 1993, *Renewable Energy: Sources for Fuels and Electricity*, Island Press, Washington, DC.

Joskow, Paul: 1995,"Utility-Subsidized Energy-Efficiency Programs," *Annual Review of Energy and the Environment* **20**: 526–534.

Keepin, Bill and Kats, Gregory: 1988, "Greenhouse Warming: Comparative Analysis of Nuclear and Energy Efficiency Abatement Strategies." *Energy Policy* **16**(6): 538–561.

Lovins, A.B.: 2005, "More Profit With Less Carbon," *Scientific American* (September), 74–82, [online] www.sciam.com/media/pdf/Lovinsforweb.pdf, accessed June 2006.

Lovins, A.B.: 1996, "Negawatts: Twelve Transitions, Eight Improvements, and One Distraction," *Energy Policy* **24**(4): 331–341, [online] www.rmi.org/images/other/Energy/U96-11_Negawatts12-8-1.pdf, accessed June 2006.

Lovins, A.B. and Cramer, D.R.: 2004, "Hypercars, Hydrogen, and the Automotive Transition." *International Journal of Vehicle Design* **35**(1/2), 50–85, [online] www.rmi.org/images/other/Trans/T04-01_HypercarH2AutoTrans.pdf, accessed June 2006.

Lovins, A.B., Datta, E.K., Bustnes, O.-E., Koomey, J.G. and Glasgow, N.J.: 2004, *Winning the Oil Endgame*, Rocky Mountain Institute, Snowmass, CO, [online] www.oilendgame.com, accessed June 2006.

Lovins, A.B., Datta, E.K., Feiler, T., Rábago, K.R., Swisher, J.N., Lehmann, A., and Wicker, K.: 2002, *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size*, Rocky Mountain Institute, Snowmass, CO, [online] www.smallisprofitable.org, accessed June 2006.

Lovins, A.B and Lovins, L.H.: 1997, "Climate: Making Sense *and* Making Money," Rocky Mountain Institute, Snowmass, CO, [online] www.rmi.org/images/other/Climate/C97-13_ClimateMSMM.pdf, accessed June 2006.

Lovins, A.B, Lovins, L.H., and Ross, L.: 1980, "Nuclear Power and Nuclear Bombs," *Foreign Affairs* **58**(5): 1137–1177 (Summer).

[MIT] Massachusetts Institute of Technology: 2003, *The Future of Nuclear Power*, Cambridge, MA: MIT, [online] http://web.mit.edu/nuclear power/

[PG&E] Pacific Gas and Electric: 2004, "The ACT^2 Project," [online] http://www.pge.com/003_save_energy/003c_edu_train/pec/info_resource/act2_proj.shtml, accessed June 2006.

Peterson, Per: 2001, "Choosing the Sources of Sustainable Energy." *Science* **291**(5510): 1899.

Schneider, M. and Froggatt, A.: 2004, "The World Nuclear Industry Status Report 2004," The Greens/EFA in the European Parliament, Brussels, www.greens-efa.org/pds/documents/greensefa_documents_106_en.pdf, accessed June 2006.

Shipley, Anna Monis and Elliot, R. Neal: 2006, "Ripe for the Picking: Have We Exhausted the Low-Hanging Fruit in the Industrial Sector," American Council for an Energy-Efficient Economy, Washington, DC, pp. 1–33.

Sioshansi, Fereidoon P: 1994, "Restraining Energy Demand," *Energy Policy* **2**2(5): 378–392.

Sørensen, Bent: 2003, *Renewable Energy: Its Physics, Engineering, Environmental Impacts, Economics and Planning* (3rd ed.), Elsevier, New York, NY.

Sutherland, Ronald J. and Taylor, Jerry: 2002, "Time to Overhaul Federal Energy R&D," *Policy Analysis* **424**: 1–21.

Taylor, Jerry: 1993, "Energy Conservation and Efficiency: The Case Against Coercion," *Policy Analysis* **189**: 1–13.

Womack, James and Jones, Daniel: 1997, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, Simon & Schuster, New York.

CHAPTER 11

ENERGY MYTH TEN – ENERGY EFFICIENCY MEASURES ARE UNRELIABLE, UNPREDICTABLE, AND UNENFORCEABLE

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11.1. INTRODUCTION

This chapter challenges those who believe that energy efficiency measures are unreliable, unpredictable, or unenforceable and that, therefore, energy efficiency cannot be relied upon as a utility system resource. This myth has been around for a long time and continues to surface periodically, despite contrary evidence and rebuttals from industry analysts (Lovins, 1994; Vine and Kushler, 1995; Geller and Attali, 2005; Sovacool, 2006).

For example, two economists at the Massachusetts Institute of Technology, Paul Joskow and Donald Marron (1993), assert that "energy conservation should be conceptualized as a customer service and a customer resource, not as a utility resource that is equivalent to a utility supply curve." Len Brookes (1990) concluded that those who advance energy efficiency as a "fifth fuel" comparable to supply perpetuate a gross fallacy, and that efficiency practices, at best, represent only "a very oblique approach. . .that seems to owe more to the current tide of green favor than to sober consideration of the facts." Geoffrey Greenhalgh (1990) warns that "presenting conservation as the equivalent to a new supply fosters the illusion that energy uses can be continued unchecked." And, more recently, the National Association of Home Builders (2005) commented that regulatory complexity and lack

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 265–287

of information among construction companies make relying on energy efficiency codes “effectively unenforceable.”

Unfortunately, a preference for supply-side options has several negative ramifications, including:

- Investment in energy efficiency by consumers (residential and non-residential) is less than optimal – in fact, in many cases, there is no investment.
- Energy efficiency is often overlooked as a solution in the energy policy arena. Instead, state and national energy solutions focus on energy supply, and energy efficiency is not seen as a reliable resource (with some exceptions – e.g., California, the Pacific Northwest, New England, and a few other states that generally have long records of successful energy efficiency programs).
- Energy efficiency is not typically seen as a solution in the environmental policy arena – instead, air quality regulators (e.g., see the Clean Air Act Amendments (CAAA) of 1990[1]) focus on traditional technical solutions (e.g., scrubbers) and supply side disincentives (e.g., NO_x and SO_2 regulations) without considering energy efficiency as a viable clean air strategy.[2]
- Energy efficiency investments by utilities are sub-optimal, in part because of doubts by utility planners and management, and in part because opponents of these programs promote this myth in order to influence regulators to not support utility energy efficiency programs. At least half the states have no real utility sector energy efficiency programs, and just 20 states account for 90% of total national spending on such programs (York and Kushler, 2005).

To examine the benefits of energy efficiency practices in greater detail, we begin our examination by first reviewing the concepts of reliability, predictability, and enforceability within the context of utility system planning and operations, for it is also important to consider these issues for supply side resources. In this section, we discuss risk and uncertainty regarding the supply side components of electricity generation, transmission and distribution, and describe how energy efficiency can help mitigate those risks. We also highlight some recent regulatory activities promoting energy efficiency explicitly for its risk-reduction value in resource procurement. This section presents a striking example of how energy efficiency has played a key role in preserving utility system reliability, in the case of the 2001 California energy crisis.

In the next section, we examine the reliability and predictability of energy efficiency from an evaluation perspective: we review the experience of evaluating energy efficiency programs and technologies in the last 20 years, the development and implementation of evaluation protocols, and key findings resulting from the evaluation of energy efficiency programs. In Section 4, we examine methods for ensuring and enforcing the performance of energy efficiency measures, programs, and portfolios. In the last section, we summarize our findings and conclude that energy savings from energy efficiency programs are sufficiently reliable, predictable, and enforceable to allow energy efficiency to be incorporated as a utility system resource.[3]

11.2. ENERGY EFFICIENCY RISK IN CONTEXT

While we recognize that there are uncertainties associated with energy efficiency as an energy resource, there are also uncertainties on the supply side. Therefore, any assessment of the reliability, predictability and enforceability of energy efficiency as a resource needs to be done in the context of how these concepts come into play in planning and operating a utility system. As the introduction illustrates, critics of energy efficiency sometimes seek to portray energy efficiency as inherently uncertain and unreliable, and supply side resources as well known and dependable. That portrayal, simply put, is false. In fact, substantial uncertainties exist regarding the planning and implementation of every utility system resource.

11.2.1 Risks and Uncertainty Regarding Electricity Generation

The most expensive aspect of an electric system is the cost associated with electricity generation. Demand side management (DSM) critics like to portray a power plant as a "reliable" and "certain" resource, in contrast to an energy efficiency program. However, while it is true that ***output*** from a power plant can be measured quite accurately, virtually every other aspect of planning for and implementing that resource is riddled with uncertainty.

Firstly, utility resource acquisition decisions are based on forecasts of future customer demand, which are inherently uncertain. So while it is true that some extra system costs can be created if an energy efficiency program delivers less savings than planned, considerable extra system costs are also created if a specific power plant resource is constructed or purchased based on a forecast that turns out to be incorrect. This situation was widely encountered in the utility industry in the 1970s and 1980s, for example, where excessively high forecasts of growth in demand for electricity led to overbuilding of electric generating plants and massive electric system cost over-runs in many states. Perhaps the most notorious example of this was in Washington State, where the Washington Public Power System (WPPS) began a construction program for as many as seven new nuclear power plants in the early 1970s. After large cost overruns and collapsing electricity demand growth in the late 1970s and early 1980s, the power system faced financial disaster and all but one of those plants was cancelled, leading to, at the time, the country's largest municipal bond default (Harden, 2006). This experience came to be called the "WHOOPS" fiasco (as a play off of the WPPS acronym) and is an enduring illustration of the risk associated with large electric system supply-side investments. In fact, consumers across the Northwest are still paying for WHOOPS in their monthly electricity bills (Harden, 2006). While WHOOPS is the most spectacular example, it is important to note that similar "boom and bust" cycles in power plant construction and cost-overruns occurred in many states during that time period, and directly produced the high electricity rates in several states that helped led to the "electric restructuring" movement of the mid-1990s.

Similar problems of uncertainty and risk surround the issue of fuel prices. Fuel purchase contracts are signed, and even power plant construction decisions are made, on the basis of projected fuel costs. Yet, uncertainty in those projections can lead to considerable risk for higher utility system costs. This has been vividly demonstrated over the last decade in the electric industry, where 95% of all new generation plants added to the grid were constructed to use natural gas. Unfortunately, the enormous price spikes for natural gas seen over the last few years have made a number of these plants uneconomic to operate, and has resulted in significant increases in market electricity prices in several areas.

Third, while the ***output*** from a plant can be measured accurately ***when it is operating***, there are at least three other significant sources of uncertainty and risk regarding a power plant. The first is the variance between projected costs and actual costs of construction. Experience has shown that there can be project delays and other unforeseen problems that can lead to considerable cost overruns and even project cancellations. Moreover, the very fact that large power plants take many years to construct, and completion dates are imprecise, adds uncertainty to the electric system.

The second source of uncertainty and risk is the issue of unplanned outages of a power plant. Electric generating plants are complex machines after all, and accidents do happen. While some of these risks can be reduced in a purchased power scenario through contractual provisions, those extra provisions increase the cost of the resource and, in any case, cannot eliminate all risk.

A third source of additional risk for electricity generation resource options that is receiving increased attention is the risk of future additional environmental costs. In particular, there is substantial risk of future costs associated with carbon emissions. Even the Electric Power Research Institute (EPRI) is engaging in the analysis of potential carbon costs, reporting for example that a $20 per ton carbon fee (not out of line with observed carbon credit costs in Europe) would add nearly two cents per kWh to the cost of electricity from a coal-fired power plant (Speckler, 2006). There are also other types of pollutants now receiving additional scrutiny and calls for further mitigation, such as mercury. This results in the additional risk of further costs being allocated to coal-fired electric generation.

11.2.2 Risks and Uncertainty Regarding Transmission and Distribution

Another important aspect of electric system costs is the transmission and distribution (T&D) system required for delivering electricity. T&D systems can be very costly, as much as hundreds of millions of dollars for a lengthy high-voltage transmission line. The Electric Power Research Institute has estimated the cost of desired transmission system upgrades nationwide at $100 billion (Reuters, 2003).

Like generation resources, T&D system resources also have significant risks. Initially, decisions regarding future T&D needs are based on forecasts of future load growth, which are subject to the same uncertainties discussed earlier in the section on electricity generation. T&D resources also have significant uncertainties regarding the costs and timeframe needed for their acquisition. A particularly important source of uncertainty in this regard is associated with the "Not In My Back Yard"

(NIMBY) phenomenon, where there is often significant local opposition to the siting and construction of new transmission lines. Local public resistance can increase uncertainty about the timing, and may increase the costs, of a transmission line project (e.g., see Meyer and Sedano, 2002).

As with electricity generation, energy efficiency and other demand-side resources can be a cost-effective way to defer or eliminate the need for T&D expansion (Kushler et al., 2005). A number of electric system jurisdictions are actively pursuing such demand-side resources to address T&D needs. Perhaps the most prominent is in the 4-state Pacific Northwest region, where the Bonneville Power Authority (BPA) in 2002 launched its ambitious "Non-Wires Solutions" project to implement alternatives to new T&D construction where possible (BPA, 2004). BPA is now committed to using its non-wires screening criteria for all capital transmission projects over $2 million, and intends for this to become an institutionalized part of its T&D system planning process. This analysis process has already been applied to several projects, and BPA is currently funding pilot tests of non-wires technologies (Kushler et al., 2005)

Box 11.1. BPA'S Non-Wires Solution

One of the more recent and most ambitious examples of an organization addressing alternatives to T&D construction is the Bonneville Power Administration (BPA). In 2002, BPA announced its Non-Wires Solutions (NWS) initiative with the goal of identifying and investigating: (1) least-cost solutions that may result in deferring potential transmission reinforcement projects; (2) ways to incorporate a specific planning methodology into the transmission planning process; (3) opportunities for and potential constraints on integrating non-wires solutions into the transmission system; (4) a set of criteria to help determine when non-wires solutions are feasible and when they are not, including developing a set of screening tools for future non-wires candidates; and (5) ways to integrate the work from this effort sufficiently early in the planning process so that that non-wires solutions can make a difference (Bonneville Power Administration,2004). BPA defines non-wires solutions as a broad array of alternatives (including but not limited to demand response (see below), distributed generation, energy efficiency measures, generation siting, and pricing strategies) that individually or in combination delay or eliminate the need for upgrades to the transmission system.

Bonneville Power Administration (BPA) is now committed to using non-wires solutions screening criteria for all capital transmission projects over $2 million so it becomes an institutionalized part of planning. An initial screening determines whether a project presents the opportunity to explore a non-wires solution. If so, BPA continues with a detailed analysis of the non-wires potential (this has been done for three projects so far). BPA is also sponsoring pilot projects to test technologies, resolve institutional barriers, and build confidence in using non-wires solutions. BPA budgeted $1 million for pilots in each of fiscal years 2005 and 2006 (Kushler et al., 2005).

11.2.3 Advantages of Energy Efficiency

Clearly, concerns about reliability, predictability, and enforceability regarding electricity resources within a utility system are not at all confined to energy efficiency programs. In fact, energy efficiency as a resource has some inherent advantages in this regard. Because energy efficiency can be acquired rapidly and in very small modular increments, energy efficiency resource acquisition can be quickly ramped up or ramped down in response to changing circumstances, and ineffective program components can be either corrected or the resources can be re-directed to more effective components.

Indeed, it is important to note that the broader issue of “risk” is what ultimately needs to be addressed. While we all acknowledge that energy efficiency programs impose certain risks on utilities, the real issue is the effects on risk of including energy efficiency programs in a utility’s resource portfolio, considering the risks associated with all of the resources in that portfolio. In a modeling study that assessed the contribution of energy efficiency programs to a utility’s resource portfolio (Hirst, 1992), the results showed that energy efficiency programs generally reduced uncertainties and that the resource portfolio with energy efficiency programs was less sensitive to changes in economic growth, fuel prices, and the capital costs of power plants than was a supply-only portfolio (i.e., no energy efficiency programs). For example, if the economy grows rapidly, substantial new construction increases both the demand for electricity and the potential for saving electricity and, therefore, energy efficiency programs targeting new construction would reduce uncertainty about load growth by reducing what Cavanagh (1986) called the “jaws of uncertainty.” Similarly, for existing customers who purchase more and larger electricity-using equipment, savings from energy efficiency programs targeting this equipment will also help to reduce uncertainty about load growth. Finally, the cost and performance of energy efficiency programs are largely independent of uncertainties about fossil-fuel prices and the construction costs of new power plants.

This risk-reducing value of energy efficiency is due to a number of factors. First, and most obviously, it avoids fuel-cost risk entirely, which is a significant advantage in this new era of high and volatile energy prices. Second, it is not dependent on a single high capital cost project like a power plant. Rather, the energy efficiency resource is composed of a large number of relatively small incremental cost projects. Finally, energy efficiency is a very flexible resource that can be acquired in larger or smaller increments in response to utility system needs, thereby dramatically reducing the risk of over-building or under-building utility system resources.

For the above reasons, system planners such as the Northwest Power and Conservation Council have found that energy efficiency resources can be extremely valuable in reducing overall system risk (Northwest Power and Conservation Council, 2005). Similarly, the California Public Utilities Commission, recognizing energy efficiency as a reliable resource, required in October 2002 that California’s investor-owned utilities should address resource adequacy by first targeting all cost-effective energy efficiency and demand-response programs before considering other options (including new generation) (CPUC, 2002). Utilities are required to conduct thorough planning processes to identify available energy efficiency opportunities and design energy efficiency budgets and programs to capture those resources.

Internationally, many countries are promoting energy efficiency as a critical resource for meeting their energy needs. For example, in 2006, the European Union's (EU) energy efficiency directive entered into force. The directive sets a target of a 9% cut in energy use over business-as-usual in the period 2008–2017. All EU member states must transpose the directive into national law by May 17, 2008.

11.2.4 Energy Efficiency to the Rescue: The California Electricity Crisis

California's strong policy decision to make energy efficiency their first priority electric resource is at least in part attributable to the fact that California experienced what is arguably the most striking example in history of energy efficiency delivering significant electric system risk-reduction benefits. That was in response to the California electricity crisis of 2000–2001.

In early 2000, the California experiment with electricity "restructuring" began to fall apart at the seams. Between the summer of 2000 and the early winter months of 2001, the electricity wholesale market became dangerously constrained and wholesale electricity prices soared. The California Independent System Operator declared over 70 days of system emergencies, and rolling blackouts were actually initiated on several occasions. Because of the interconnectedness of the electricity grid, the "ripple effects" of the California system crisis were felt throughout the Western states. Electricity wholesale prices soared throughout the region, and system reserve margins were constrained. In January and February 2001, the California Energy Commission (CEC) projected electricity supply and demand for the summer of 2001 under various temperature scenarios, and analyses suggested that the State could face a potential shortfall of 5,000 MW during the months of June through September (CEC, 2001).

In reaction to this unprecedented "electricity crisis," California responded with a historic series of demand-side policy initiatives. California policymakers and utility regulators established a substantial set of policies and programs that involved significant additional funding for existing energy efficiency programs and the development of a large number of new programs. In all, more than $1.3 billion in funding was authorized for demand reduction initiatives in 2001, representing a 250% increase over the spending in 2000 (Messenger, 2001). In particular, the degree of policy emphasis and the amount of funding provided for utility-sector energy efficiency were without parallel in U.S. history. The total funding allocated for energy efficiency in California for 2001 (over $900 million, excluding load management funding) was roughly equivalent to the total energy efficiency program spending in all other states combined (Kushler and Vine, 2003).

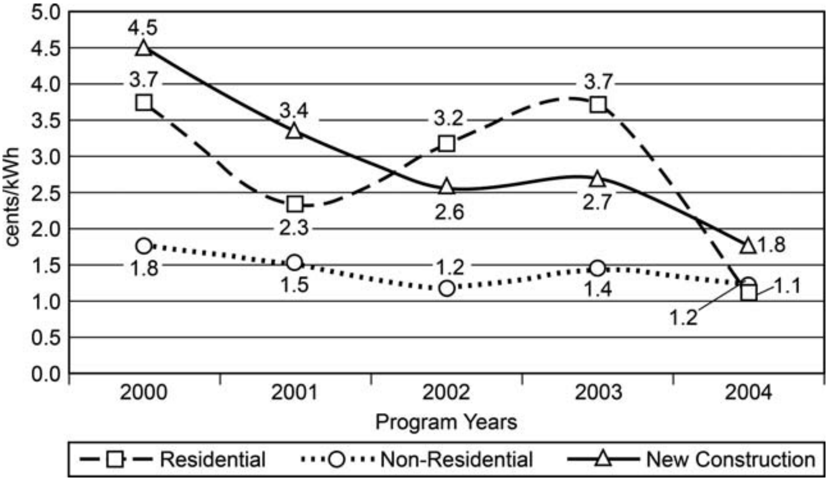

Figure 11.1. Summary of cost effectiveness by sector for PG&E, SCE, & SDG&E for program years 2000–2004 (Based on Rogers et al. 2005)

By virtually all indicators, the totality of this effort was extremely successful. The synergistic effect of all the California programs and policies was immense. In 2001, California averaged a 10% cut in peak demand (averaging 4,200 MW) during the summer months (with a record reduction of 14% in June representing approximately 4,750 MW), and overall electricity use declined in 2001 by 6.7% (representing approximately 16,400 GWh), after adjusting for economic growth and weather (CEC 2002; Goldman et al., 2002). A subsequent comprehensive evaluation found that these energy efficiency programs were very cost effective, providing electricity savings at a lifetime levelized cost[4] of $.03 per kWh (Global Energy Partners, 2003). Perhaps the most meaningful result of all was that California experienced no further incidences of rolling blackouts. It is no exaggeration to say that energy efficiency and conservation "kept the lights on" in California. And these programs remain cost effective and provide a relatively inexpensive source of energy for California consumers (Figure 11.1).

11.3. AN EVALUATION PERSPECTIVE ON RELIABILITY/PREDICTABILITY OF ENERGY EFFICIENCY

11.3.1 Short History of Evaluation of Energy Efficiency Programs

The evaluation of energy efficiency programs has a rich and extensive history, dating back to the early 1980s. Initially, much of this evaluation work was driven by academic and research interests. Indeed, the first energy efficiency and evaluation conferences in the early 1980s were largely populated by representatives of universities and government agencies.

As energy efficiency began to be recognized as a utility system resource, the nature of the evaluation focus evolved. In part as a response to the uncertainties about this new and unfamiliar "resource," energy efficiency programs were subjected to a very high level of scrutiny. It is also fair to say that opponents of these programs (e.g., large industrial customer associations that resist paying for these programs in their rates and frequently those utilities who don't want to experience the revenue loss from reduced sales due to energy efficiency) often challenged the programs in rate cases and demanded that program evaluations be conducted. As a result of these factors, regulatory commissions frequently required program evaluation and the review of evaluation results in commission hearings.

Ultimately, the results of all this scrutiny have been beneficial. By now, over 1,000 evaluation studies have been prepared in the United States and the energy savings of energy efficiency programs have been closely reviewed in contested regulatory hearings in dozens of states. In the 21st century, we now have an entire energy evaluation industry and dedicated professional organizations continuing to enhance the methods, standards, and conduct of energy program evaluation. The results of this work are published in peer-reviewed journals and conference proceedings.

One of the most highly regard conferences in this area is the International Energy Program Evaluation Conference (IEPEC), a biennial professional conference whose purpose is to provide a forum for the presentation, critique and discussion of objective evaluations of energy programs.[5] The core product of this conference is the documentation of unbiased, peer-reviewed evaluations that establish the basis for accurate information and provide credible evidence of program success or failure. Conferences have been held in 1984, 1985, and every 2 years thereafter.

A wide range of evaluation methodologies has been developed and refined over the past 30 years to estimate energy savings with acceptable levels of precision. These evaluation techniques have featured many sophisticated methods to rigorously assess energy efficiency impacts, including quasi-experimental methods where program participants are compared to a comparison group of non-participants, direct measurements of "before and after" energy use, estimation of "free riders," utility bill analysis with adjustments for variations in weather and other factors where appropriate, accounting for the persistence of energy savings through measure retention studies and analyses of energy usage over time, and the analysis of program spillover and market transformation. All of these concepts are well established and widely used to estimate the energy savings of energy efficiency programs. A report discussing these issues was recently prepared for the California Public Utilities Commission (TecMarket Works Framework Team, 2004).

Techniques for evaluating energy savings programs and measures have evolved considerably over the years and are fairly mature in many respects. However, the professional field continuously engages in monitoring and development of evaluation techniques and practices. The California Measurement Advisory

Committee (CALMAC) maintains and periodically updates detailed energy efficiency program evaluation studies and are published and available on their website (www.calmac.org). The Consortium for Energy Efficiency also maintains an evaluation database containing program evaluations that are not in the CALMAC database; these studies are available on their website (www.cee.org).

11.3.2 Development of Evaluation Protocols

Standardized procedures for the measurement and verification (M&V) of savings from energy efficiency are key tools for ensuring that energy savings are reliable and predictable. Energy service companies (ESCOs) have led the effort to verify, rather than estimate, energy savings, particularly where public and utility ratepayer funds are involved. If savings from energy efficiency measures were deemed to be too risky, unreliable, or unpredictable, then there would be no ESCO industry. The business success of the ESCO industry tells a different story. For example, the total amount of ESCO activity in the United States was between $1.8 billion and $2.1 billion in 2000 (Goldman et al., 2005), and the total amount of ESCO activity outside the United States was between $560 million and $620 million in 2001 (Vine, 2005). And in the United States, the federal government has been a key source of ESCO industry growth since the mid-1990s, especially through the Federal Energy Management Program (Goldman et al., 2005).

The ESCOs' effort to standardize the measurement of savings gained powerful momentum when U.S. electric utilities turned to private providers for firm demand-side capacity. With utilities under regulatory pressure to invest in efficiency programs with strictly verifiable results, protocols and equipment to measure energy savings cost-effectively were developed. By combining technical accuracy with cost-effectiveness, these protocols and guidelines marked a notable improvement over previous practices. They have largely replaced the less accurate use of engineering estimates for most energy efficiency measures in buildings.

One of the most important M&V protocols is the one developed by the U.S. Department of Energy (DOE) for measuring and verifying energy savings from energy-efficiency projects: the International Performance Measurement and Verification Protocol (IPMVP) (DOE,2000).[6] North America's energy service companies have adopted the IPMVP as the industry standard approach to measurement and verification. States ranging from Texas to New York require the use of the IPMVP for state-level energy efficiency retrofits. The U.S. Federal Government, through the DOE's Federal Energy Management Program, uses the IPMVP approach for energy retrofits in Federal buildings. Finally, countries ranging from Brazil to the Ukraine have adopted the IPMVP, and the Protocol has been translated into many languages.

A key element of the IPMVP is the definition of two M&V components: (1) verifying proper installation and the measure's potential to generate savings; and (2) measuring actual savings. The IPMVP was built around a common structure of four M&V options based on the two components to M&V defined above.

Table 11.1. Overview of IPMVP's M&V options

M&V Options	How savings are calculated
Option A: • Focuses on physical inspection of equipment to determine whether installation and operation are to specification. Performance factors are either stipulated (based on standards or nameplate data) or measured. • Key performance factors (e.g., lighting wattage or "motor" efficiency) are measured on a snapshot or short-term basis. • Operational factors (e.g., Lighting operating hours or motor runtime) are stipulated based on analysis of historical data or spot/short-term measurements.	Engineering calculations or computer simulations based on metered data and stipulated operational data.
Option B: • Intended for individual energy conservation measures (ECMs) (retrofit isolation) with a variable load profile. • Both performance and operational factors are measured on a short-term continuous basis taken throughout the term of the contract at the equipment or system level.	Engineering calculations after performing a statistical analysis of metered data.
Option C: • Intended for whole-building M&V where energy systems are interactive (e.g. efficient lighting system reduces cooling loads) rendering measurement of individual ECMs inaccurate. • Performance factors are determined at the whole-building or facility level with continuous measurements. • Operational factors are derived from hourly measurements and/or historical utility meter (electricity or gas) or sub-metered data.	Engineering calculations based on a statistical analysis of whole-building data using techniques from simple comparison to multivariate (hourly or monthly) regression analysis.
Option D: • Typically employed for verification of saving in new construction and in comprehensive retrofits involving multiple measures at a single facility where pre-retrofit data may not exist. • In new construction, performance and operational factors are modeled based on design specification of new, existing and/or code complying components and/or systems. • Measurements should be used to confirm simulation inputs and calibrate the models.	Calibrated energy simulation/modeling of facility components and/or the whole facility; calibrated with utility bills and/or end-use metering data collected after project completion.

Source: Adapted from USDOE (1997)

The purpose of providing several M&V options is to allow the user flexibility in the cost and method of assessing savings (Table 11.1). The options differ in their approach to the level and duration of the verification measurements. None of the options are necessarily more expensive or more accurate than the others. Each has advantages and disadvantages based on site-specific factors and the needs and expectations of the customer.

Protocols and procedures for the measurement and evaluation of utility energy-efficiency programs have also been developed at the state level by public utility commissions. For example, in the 1990s, in response to the shareholder earnings mechanisms established for the four largest investor-owned utilities to acquire energy efficiency, California developed one of the most rigorous measurement and evaluation protocols (see Box 11.2).

Box 11.2. The Evaluation of Energy-Efficiency Programs in California in the Protocol ERA (1994–1997)

California is widely recognized as the state having the most experience in evaluating utility energy-efficiency programs in the United States. The depth and rigor of evaluation has varied over time, reflecting different regulatory environments and market structures for electricity in California (Vine et al., 2006). In the Protocol ERA (1994–1997), protocols and procedures were developed in response to the shareholder earnings mechanisms established for the four largest investor-owned utilities to acquire energy efficiency. From 1994 to 1998, the California utilities completed hundreds of evaluation studies and earnings claims for their programs were based on adopted ex-post agreements identified in the protocols.

The utility program evaluations were conducted by utility staff or contractors to the utilities, and the results from these evaluations were filed with the California Public Utilities Commission (CPUC). The CPUC's Office of Ratepayer Advocates (ORA) reviewed these studies, the claimed shareholder earnings, and proposed changes or additions to the protocols. Two types of review were conducted by ORA: (1) verification of participation: a review of the utility's files to make sure all participants are in the utility's data base, and a review of the files for a random sample of participants (in some cases, onsite visits were conducted on a small sample of nonresidential customers); and (2) for the larger programs, ORA prepared "review memos" that were based on a review of the evaluation studies: if problems were encountered, utility data files were requested for conducting a "replicate analysis."

If ORA could not replicate the utility analysis, then ORA would challenge the utility's results. If ORA could replicate the utility's analysis but there were problems, then more information was requested and more analyses were conducted. If ORA could replicate the utility's analysis and it was reasonable, then there was no basis for challenging the utility's results. At the end of each year, ORA filed a report with the CPUC which contained recommendations on the utility evaluation studies and findings. A case management process was then conducted to see if the differences between the ORA and the utilities could be resolved. If not, then hearings were held at the CPUC to resolve the differences. At the end of the process, the Administrative Law Judge at the CPUC issued a decision on the utilities' earning claims and associated evaluation studies (where appropriate).

Since 1998, several significant program design and implementation changes have occurred, reflecting market transformation goals (1998–1999) and the energy crisis of 2000/2001. In 2002, the CPUC adopted a new Energy Efficiency Policy Manual that required utilities to use the IPMVP for M&V. And in 2005, the CPUC started a process of developing new M&V protocols for energy efficiency programs – these protocols were adopted by the CPUC in 2006 (TecMarket Works Framework Team, 2006).

Evaluations of large-scale utility energy efficiency programs, in many cases using measured rather than estimated savings data, have found that these programs save energy and are cost effective. For example, a review of 40 large-scale commercial sector energy efficiency programs implemented during the early 1990s found that they saved electricity at an average cost of $0.032 per kWh, well below the cost of supplying electricity (Eto et al.,1996). This study relied on post-program evaluations of energy savings, and included all utility costs as well as customer costs in its analysis.

11.3.3 Ex-Ante Versus Ex-Post Estimates of Energy Savings

One measure of reliability of energy savings from energy efficiency measures is how well ex-ante estimates of energy savings (forecasted prior to measure installation and typically based on engineering calculations) compare with ex-post impact estimates of savings (based on post-implementation measurement). A realization rate is calculated as the ex-post estimate of net savings divided by the ex-ante estimate of net savings. Net savings refer to the program impacts over-and-above naturally occurring energy efficiency. Net savings can be smaller than gross savings to the extent that some participants would have purchased and installed new energy efficiency measures without the program ("free riders"). Net savings can also be larger than gross impacts to the extent that the program induces additional customer investments in energy efficiency measures outside of the program due to changes in the market place ("market transformation").

Most realization studies occurred in the early 1990s, particularly in California. With the advent of shareholder incentives during this period, the California Public Utilities Commission insisted on more rigorous terms and conditions for the measurement and verification of costs and benefits, leading to comparisons of ex-ante and ex-post impact estimates (Vine et al., 2006). For example, in a study of 158 California's energy efficiency programs and program segments operating between

1990 and 1992, the mean realization rate was 112% (Brown and Mihlmester, 1995). Overall, these results suggest that California's energy efficiency programs operating between 1990 and 1992 outperformed typical programs from the 1980s, which often fell short of their expected savings by 30 to 70%.[7] The low realization rates in the early years were primarily due to ex-ante estimates that were based on broad predictions using simple assumptions. Since that period, the calculation of projected (ex-ante) savings numbers has become very refined (due to the findings from past evaluations), so that the realization rates are much better now. In another study of realization rates, this time a study of four Massachusetts' utility programs operating between 1990 and 1993, the overall realization rate was 80%[8] – an impressive result given that these programs were significantly ramped up over a very short time period with little previous in-field utility experience with full-scale program implementation to inform planning estimates (Coakley and Schlegel, 1995).

In conclusion, energy savings projections now are much more accurate than they used to be, because we have decades of data from experience in the field. Also, with improvements in program design over the years, especially toward increasing market transformation and "spillover" effects, it is not at all uncommon for programs now to have realization rates in excess of 100%. With these better savings projection data and evaluation techniques now available, and proper ongoing evaluation and monitoring, there is little reason for concern that a well-designed suite of energy efficiency programs won't achieve their projected savings (Box 11.3).

Box 11.3. The Evaluation of Energy-Efficiency Programs in California (2006–2008)

The California Public Utilities Commission (CPUC) reviewed ex-ante and ex-post impact estimates for the energy efficiency programs implemented by California's investor-owned utilities. The CPUC concluded that the ex-post re-evaluation of lifecycle kW and kWh savings conducted for the pre-1998 programs did not produce significant adjustments to ex-ante forecasts of net resource benefits once the actual program costs and program participation had been verified (CPUC, 2005). They believed that the "feedback process" between program planning and evaluation was critical to this finding as ex-post study results have been incorporated into subsequent program planning (and resource planning assumptions) and will be required to do so in the future. As a result, the CPUC has become more confident in the reliability of energy savings estimates from these programs.

For the energy efficiency programs that are to be implemented in the 2006–2008 time period, the CPUC required that the performance basis for resource programs (i.e., those saving kWh, kW, or therms) be subject to the following (CPUC, 2005):

- A true-up of ex-ante (pre-installation) assumptions for program participation (e.g., types and number of measures or equipment) with actual participation verified on an ex-post basis (i.e., during and after program implementation).

- A true-up of ex-ante program costs assumptions with actual expenditure levels.
- As a general policy, ex-post re-evaluation of per unit kWh, kW, and therm savings through load impact studies. An exception to the general policy may be appropriate for measures and/or programs for which there are well-established ex-ante values with a high degree of confidence, and low external sources of variability that could influence the energy savings.
- Persistence studies will not be tied to the performance basis, but shall still be performed to inform future planning. This policy shall be revisited and revised, as appropriate, if there is evidence at a future date that the results of persistence studies are significantly different from the ex-ante estimates.

11.4. ENSURING AND ENFORCING PERFORMANCE OF ENERGY EFFICIENCY MEASURES, PROGRAMS, AND PORTFOLIOS

The development of rigorous evaluation practices and protocols, along with years of experience in assessing the impacts and results of energy efficiency programs, has done much to improve the ability of program planners and managers to accurately estimate both individual measure and aggregate program impacts. The development of protocols has also helped to establish program goals and implement the programs so as to achieve established targets. In this section, we examine some primary methods for ensuring that energy efficiency measures, programs, and portfolios achieve projected savings.

The exact mechanism and approach taken to ensuring and enforcing energy efficiency goals and performance varies according to a number of factors, such as: (1) the reason a given energy efficiency action or investment is taken, (2) who has a stake in the energy savings, and (3) the possible ramifications of not achieving projected savings or goals. These factors all will determine the degree of energy savings "enforceability" that is required and what consequences might be incurred for any failure to achieve projections or established targets.

Below are the primary mechanisms or models for ensuring and enforcing energy efficiency targets and performance. These categories are based on the primary "driver" behind the individual action.

11.4.1 Contractual Terms

Individual customers (which can include large businesses, institutions and governments) can enter into agreements with ESCOs or similar contractors to perform tasks and make system improvements that yield energy savings. Such contracts can take numerous forms. "Performance contracting" is common; such agreements typically "guarantee" or "share" savings such that the ESCO is paid out of savings achieved after the work is performed and the selected energy efficiency measures are installed. The performance contract includes terms as to how the savings are to be measured and verified. This may be as simple as reading the utility meter (possibly making some adjustments for weather variations, for example) to installing dedicated data loggers or other devices that measure actual energy use. Enforcement in these cases is contractual – the provider of services (i.e., the ESCO) is paid according to the results achieved. Clearly, the provider has incentives to achieve the estimated savings and be able to verify that such savings indeed are achieved. Goldman et al. (2005) show that the ESCO industry in the United States has grown rapidly and matured to be about a $2 billion industry in 2000. Performance contracts constitute a significant share of this total investment – about 50% according to estimates in this study. The Energy Policy Act of 2005 (Public Law, 109–158) reauthorized the Energy Savings Performance Contract (ESPC) program, which allows private contractors to help Federal agencies improve the energy efficiency of their facilities through performance contracting.

Performance contracts generally involve only two parties – the customer and the service provider. However, there also are utility and public benefits programs that may provide funding and other services (e.g., marketing and technical assistance) to support performance contracting. In these cases, the program administrator is another stakeholder in the outcome of the individual transactions between ESCOs and customers. Consequently, the program administrators are likely to require measurement and verification for performance contracts enacted by and supported by the program. This adds an additional measure of enforcement and assurance that estimated energy efficiency savings are realized.

Contracts and market transactions for energy efficiency savings also can occur within electricity markets. “Demand response” programs have emerged as a market mechanism to address capacity needs – both in the short- and long-term, which largely build from “load management” approaches established in the 1980s and 1990s. While clearly demand response and energy efficiency are related, there has been relatively little research to examine this relationship (York and Kushler, 2005). Demand response seeks to reduce peak power demands (MW) or drop loads to prevent grid contingencies, while energy efficiency seeks to reduce energy use (MWh) during all times of equipment operation. However, many of the same methods used to measure and verify energy savings also can be used to measure and quantify demand savings. “Incentive-based” demand response programs (i.e., programs that pay participating customers to reduce their loads at times requested by the program sponsor) necessitate rigorous measurement and verification because payment to participating customers depends on such accounting. Failure to provide savings can result in the imposition of financial penalties.

11.4.2 Codes and Standards Enforcement

Building energy codes and appliance standards are mechanisms used to establish minimum energy efficiency levels in buildings and energy-using equipment, respectively. Building codes are typically a combination of prescriptive measures (e.g., specifying minimum levels of attic and wall insulation) and performance criteria (e.g., maximum lighting load in kW/ft^2). Appliance standards establish a minimum level of efficiency that must be achieved for a given type of appliance or end-use equipment, such as refrigerators or air conditioners.

Building code enforcement is the responsibility of government agencies or public authorities. Typically, compliance with energy codes may be performed in conjunction with other applicable building codes, such as fire and safety. Building code officials check for compliance by review of building plans and specifications prior to construction, and then may perform follow-up on-site reviews after construction is complete. Non-compliance may result in fines and other penalties, as well as taking actions as dictated to achieve compliance. Enforcement of building energy codes can be a daunting challenge, especially as buildings have become more complex and performance-based compliance approaches have become more popular. Smith and McCullough (2001) examine this problem and provide case studies of leading jurisdictions that use third-party enforcement strategies. They conclude that successful third-party strategies require clear definition of roles and responsibilities of involved parties along with training and technical assistance products and services for building professionals and building department staff.

In the United States, the enforcement of federal appliance standards is the responsibility of the U.S. Department of Energy (DOE). In order to ensure that manufacturers are complying with standards requirements, DOE established testing and monitoring procedures. However, for the most part, DOE relies on self-enforcement: manufacturers test their own products and report data on efficiency to DOE (Lin and Biermayer, 2006). On the other hand, competing companies often test each other's products and report to the DOE if a competitor is not in compliance. DOE also has penalties and consequences for non-compliance (e.g., penalties of up to $100 for each violation). The purpose of the fine is to ensure that manufacturers will comply, but not to put them out of business.

11.4.3 Regulatory and Administrative Review

Utilities and public benefit organizations in the United States spent a total of $1.4 billion[9] on energy efficiency programs in 2004 (York and Kushler, 2006). This is a small amount (0.7%) relative to the size of the electric utility industry, which recorded total operating expenses in 2004 of $207 billion (EIA, 2005). Oversight and financial responsibility for program spending varies from jurisdiction to jurisdiction, but generally there is some public authority or agency that oversees program administration. Such authorities typically are public service commissions, but also may be public power governing boards, state energy offices, or other state organizations. The public authorities that oversee energy efficiency programs are responsible to ensure that program spending is prudent, which generally means that some type of ex-post evaluation will be required to assess program results and estimate savings impacts.

Utility regulators have a variety of mechanisms that they can employ to ensure that energy savings targets from utility programs are achieved. Recovery of program costs is one such mechanism: if a utility program fails to achieve a specified level of savings (e.g., meeting at least 70% of the energy savings target), costs for the program may be disallowed for cost recovery through utility rates, meaning that shareholders would bear these costs (or possibly a share of the costs).

While the threat of disallowance of energy efficiency program costs may motivate utilities and other program providers to achieve target savings levels, experience with utility energy efficiency programs suggests that imposition of such penalties is rarely used. Rather, the failure to reach desired savings levels in a given program in a given year is typically addressed prospectively by requiring fundamental changes in the program approach and structure, in order to improve the program's performance and achieve desired savings levels in future years. In this way, evaluation is used to monitor program performance and signal necessary changes. For example, one major energy efficiency program administrator, the Northwest Energy Efficiency Alliance (NEEA), notes that it seeks to integrate evaluation closely into final program designs and implementation so projects can be managed adaptively to achieve their goals in a changing market (NEEA, 2000).

"Diversification" and "portfolio management" have emerged as mechanisms employed by program providers to address the uncertainty of achieving energy savings for programs. Program providers recognize that, across a set of programs, there may be individual programs that fail to reach established targets. However, there are also likely to be other programs that exceed targets, so that, in aggregate, a program portfolio reaches its overall targets. Utilities and program providers in states with long records of successful energy efficiency programs typically employ this approach. Their experience also helps ensure that best practices are followed for any given program, which in turn helps programs to achieve target savings levels cost-effectively. For example, the New York State Energy Research and Development Authority (NYSERDA), a state organization responsible for administration of New York's public benefits energy programs, uses evaluation in this strategic sense. NYSERDA requires routine and regular evaluation of individual programs as well as its entire portfolio or programs, known as "New York State Energy$mart," to monitor results and adjust program plans and operations (NYSERDA, 2005).

Another regulatory mechanism is to provide utilities with "performance incentives" for achieving target savings levels. For example, in Massachusetts, regulated distribution utilities are required to offer energy efficiency programs for their customers. In addition to cost recovery for program expenses, the utilities can earn up to an additional 5.5% of program expenditures for reaching a specified percentage of program targets. After the programs have been implemented, the utilities measure the program savings. The incentive is based on the results of this measurement and evaluation phase. The incentive is based on a combination of elements including energy savings, benefit-cost, and market transformation results.

Non-utility providers of energy efficiency programs also may be subject to cost-recovery and performance incentives based on measurement and verification of program savings relative to established targets. For example, Efficiency Vermont, a state-wide provider of energy programs and services, is subject to review by the Public Service Board of Vermont. Efficiency Vermont's contract is performance based; there are both energy and demand savings targets built into the contract, as well as targets for net societal benefits, market shares for selected measures, and other quantifiable results. The Public Service Board of Vermont administers evaluations of Efficiency Vermont's programs to measure and verify results.

An emerging trend in utility-sector energy efficiency programs is the creation of "energy efficiency resource standards (EERS)," which are electric and/or natural gas energy savings targets established for utilities – generally some percentage targets or prescribed levels of energy savings (kWh or therms) by certain dates (e.g., 10% savings by 2015). They are analogous to "renewable energy portfolio standards," which are in place in numerous states. A growing number of states are implementing EERS, often in conjunction with more flexible options for meeting the targets, including use of market-based trading systems for energy efficiency savings credits. States that have taken this approach include California, Colorado, Connecticut, Hawaii, Nevada, Pennsylvania, Texas, and Vermont. Illinois and New Jersey are planning to implement EERS programs soon. A recent report (Nadel, 2006) reviews experiences to date with EERS across the United States (Figure 11.2). The EERS programs to date show that many approaches are possible and that different approaches will likely make sense in different states based on the different situations and organizations involved. In addition, in the two states that have been

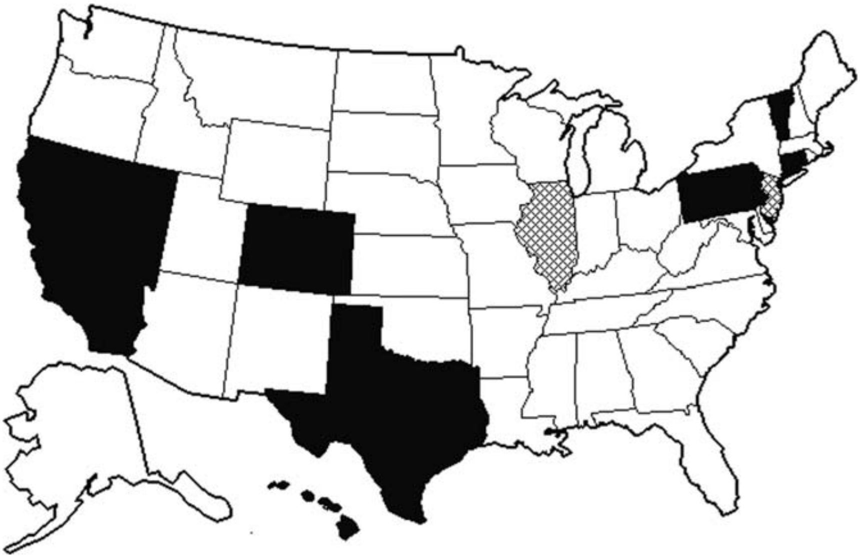

Figure 11.2. States that have or are actively considering energy efficiency resource standard policies (Nadel, 2006)

Note: Dark states currently have EERS. Crosshatched states have pending EERS implementing EERS policies for several years (Texas and Vermont), the programs are widely perceived to be working well and providing significant energy impacts.

11.5. SUMMARY

This paper addresses the myth that energy savings from energy efficiency measures are not reliable, predictable, or enforceable and that, therefore, energy efficiency cannot be relied upon as a utility system resource. Critics question whether a utility company, for example, can rely on the energy savings from an energy efficiency program as part of their resource procurement plan with the same level of confidence as they rely on the output from a natural gas power plant.

We reviewed the concepts of reliability, predictability, and enforceability within the context of utility system planning and operations, and we concluded that energy efficiency programs can reduce uncertainties in utility system planning and operations, especially when compared to uncertainties on the supply side (e.g., delays in the construction of power plants, increasing costs of power plant construction, variable fuel prices, and the costs and timing of T&D projects). We next examined the reliability and predictability of energy efficiency from an evaluation perspective, and we concluded that the maturation of a professional evaluation industry and the development of evaluation protocols have made energy savings estimates more reliable and predictable. Finally, we examined several methods for ensuring and enforcing the performance of energy efficiency measures, programs, and portfolios, and we concluded that there are sufficient incentive and disincentive mechanisms in place to ensure the energy savings from these measures.

Throughout this chapter, we have provided examples of how energy efficiency is being regarded as a reliable energy resource by policymakers and regulators at the state and federal levels. We expect other states to increase their support of energy efficiency as the demand for energy services continues to grow and environmental challenges (such as climate change and air quality) continue. And the evaluation community will continue to be involved in these discussions in order to provide the mechanisms for ensuring that the savings from energy efficiency programs are reliable, predictable, and enforceable.

NOTES

[1] The CAAA did include provisions to award sulfur dioxide "allowances" (tradable credits) for energy efficiency, but this was a very small part of the planned program and was not very effective in promoting additional levels of energy efficiency as intended.

[2] Fortunately, this is changing slightly. For example, energy efficiency can be used as (1) a control measure to reduce emissions in State Implementation Plans (SIP) under the Clean Air Act, (2) as a compliance strategy in the Conservation and Renewable Energy Reserve to reduce SO_2under the Clean Air Act, (3) as an option in the Energy Efficiency/Renewable Energy Set-Aside in the NO_X Budget Trading Program established by the U.S. Environmental Protection Agency in the NO_X SIP Call, and (4) in several other programs (Vine,2003). These all represent promising openings for energy efficiency, although they have seen limited use to date.

[3] This chapter focuses on energy efficiency and does not address demand response programs, demand response programs seek to reduce peak demands during times when reliability may be threatened or wholesale market prices are high (York and Kushler, 2005). While programs can be designed to target both demand response and energy efficiency, such integration has rarely been attempted thus far. Also, there is much less of a research and evaluation record regarding demand response programs than there is for energy efficiency.

[4] Levelized cost is the cost per kWh saved, taking into account all of the kWh saved by the program over the lifetime of the measures installed in comparison to the total cost of delivering the program. The value of costs and savings are adjusted to reflect the timing of those costs and savings (i.e., the value in future years is discounted for inflation). This results in a single number that expresses the relative cost of the resource over the lifetime of the resource.

[5] For more information on IEPEC, or to get past conference proceedings, go to their web site: www.iepec.org. In the interest of full disclosure, two of the authors of this chapter (Kushler and Vine) are past Board Presidents of this non-profit organization.

[6] The protocol can be downloaded from the following site: http://www.ipmvp.org.

[7] Even when realization rates were 70% or less, the programs were cost effective.

[8] As noted before, even with a realization rate of 80%, these programs were cost effective.

[9] While this amount of funding does support some important energy efficiency programs in a number of states (at least 20 at last count), it still represents less than one percent of the total annual revenues of the U.S. electric utility industry.

REFERENCES

[BPA] Bonneville Power Authority: 2004, *Transmission Planning Through a Wide-Angle Lens: A Two-Year Report on BPA's Non-Wires Solutions Initiative*, Bonneville Power Authority, Portland, OR, USA.

Brookes, L.: 1990, "The Greenhouse Effect: The Fallacies of in the Energy Efficiency Solution," *Energy Policy* **18**: 199–201.

Brown, M. and Mihlmester, P.: 1995, "Actual Vs. Anticipated Savings from DSM Programs: An Assessment of the California Experience," International Energy Program Evaluation Conference, *Proceedings of the 1995 International Energy Program Evaluation Conference*, Chicago, IL, USA, pp. 295–301.

[CEC] California Energy Commission: 2001, *Emergency Conservation and Supply Response 2001*, Report P700-01-005F, California Energy Commission, Sacramento, CA, USA.

[CEC] California Energy Commission: 2002, *The Summer 2001 Conservation Report*, California Energy Commission, Sacramento, CA, USA.

[CPUC] California Public Utilities Commission: 2002, *Decision 02-10-062, Interim Opinion*, 24 October, 2002, California Public Utilities Commission, San Francisco, CA, USA.

[CPUC] California Public Utilities Commission: 2005, *Decision 05-04-051, Interim Opinion: Updated Policy Rules for Post-2005 Energy Efficiency and Threshold Issues Related to Evaluation, Measurement and Verification of Energy Efficiency Programs*, 21 April, 2005, California Public Utilities Commission, San Francisco, CA, USA.

Cavanagh, R.: 1986, "Least-Cost Planning Imperatives for Electric Utilities and their Regulators", *Harvard Environmental Law Review* **10**(2): 299–344.

Coakley, S. and Schlegel, J.: 1995, "Comparing Electric Utility DSM Planning and Evaluation Estimates in Massachusetts: Are We Getting What We Planned For?" International Energy Program Evaluation Conference, *Proceedings of the 1995 International Energy Program Evaluation Conference*, Chicago, IL, USA, pp. 303–308.

[EIA] Energy Information Administration: 2005, "Revenue and Expense Statistics for Major U.S. Investor-Owned Electric Utilities," Table 8.1, *Electric Power Annual 2004*, Energy Information Administration, Washington, DC, USA.

Eto, J., Vine, E., Shown, L., Sonnenblick, R., and Payne, C.: 1996, "The Total Cost and Measured Performance of Utility-Sponsored Energy Efficiency Programs", *The Energy Journal* **17**(1): 31–51.

Geller, H. and Attali, S.: 2005, *The Experience with Energy Efficiency Policies and Programmes in IEA Countries: Learning from the Critics*, IEA Information Paper, International Energy Agency, Paris, France.

Global Energy Partners, LLC: 2003, *California Summer Study of 2001 Energy Efficiency Programs, Final Report*, Global Energy Partners, Lafayette, CA.

Goldman, C., Barbose, G., and Eto, J.: 2002, "California Customer Load Reductions during the Electricity Crisis: Did They Help to Keep the Lights On?" *Journal of Industry, Competition and Trade* **2**(1/2): 113–142.

Goldman, C., Hopper, N., and Osborn, J.: 2005, "Review of US ESCO Industry Market Trends: An Empirical Analysis of Project Data," *Energy Policy* **33**: 387–405.

Greenhalgh, G.: 1990, "Energy Conservation Policies," *Energy Policy* **18**: 296–299.

Harden, B.: 2006, "In the Northwest, Nuclear Power Takes a Hit," *Washington Post*, in washingtonpost.com, 22 May, 2006.

Hirst, E.: 1992, *Effects of Utility DSM Programs on Risk*, Report ORNL/CON-346, Oak Ridge National Laboratory, Oak Ridge, TN, USA.

Hopper, N., Goldman, C., McWilliams, J., Birr, D., and McMordie Stoughton, K.: 2005, *Public and Institutional Markets for ESCO Services: Comparing Programs, Practices and Performance*, LBNL-55002, Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Joskow, P. and Marron, D.: 1993, "What Does a Negawatt Really Cost? Further Thoughts and Evidence", *The Electricity Journal* **6**(6): 14–26.

Kushler, M. and Vine, E.: 2003, *Examining California's Energy Efficiency Policy Response to the 2000/2001 Electricity Crisis: Practical Lessons Learned Regarding Policies, Administration, and Implementation*, American Council for an Energy Efficient Economy, Washington, DC, USA.

Kushler, M., York, D., and Vine, E.: 2005, "Energy-Efficiency Measures Alleviate T&D Constraints", *Transmission and Distribution World* **57**(4): 32–41.

Lin, J. and Biermayer, P.: 2006, "Enforcement and Compliance of Efficiency Labels and Minimum Energy Efficiency Standards for Household Appliances", American Council for an Energy Efficient Economy, *Proceedings of the 2006 Summer Study on Energy Efficiency in Buildings*, Washington, DC, USA.

Lovins, A.: 1994, "Apples, Oranges, and Horned Toads: Is the Joskow & Marron Critique of Energy Efficiency Costs Valid?" *The Electricity Journal* **7**(4): 29–61.

Messenger, M.: 2001, "Balancing Customer Needs with System Reliability Concerns in California", American Council for an Energy Efficient Economy, presentation at the ACEEE National Conference on Energy Efficiency and Reliability, Berkeley, CA, USA.

Meyer, D. and Sedano, R.: 2002, "Transmission Siting and Permitting," Appendix E in *National Transmission Grid Study*, U.S. Department of Energy, Washington, DC, USA.

Nadel, S.: 2006, *Energy Efficiency Resource Standards: Experience and Recommendations*, ACEEE Report E063, American Council for an Energy-Efficiency Economy, Washington, DC, USA.

National Association of Home Builders: 2005, *Energy*, [online] http://www.nahb.org/generic.aspx?sectionID=206&genericContentID=3115, accessed July 2006.

[NYSERDA] New York State Energy Research and Development Authority: 2005, *New York Energy \$mart^{SM} Program Evaluation and Status Report, Final Report*, New York State Energy Research and Development Authority, Albany, NY, USA.

[NEEA] Northwest Energy Efficiency Alliance: 2000, *Strategic Plan*, Northwest Energy Efficiency Alliance, Portland, OR, USA.

Northwest Power and Conservation Council: 2005, *The Fifth Northwest Electric Power and Conservation Plan*, Northwest Power and Conservation Council, Portland, OR, USA.

Reuters: 2003, "Utility Group: Power Grid Upgrade May Cost $100 billion," 25 August, 2003.

Rogers, C., Messenger, M., and Bender, S.: 2005, *Funding and Savings for Energy Efficiency Programs for Program Years 2000 through 2004*, Staff Paper, California Energy Commission, Sacramento, CA, USA.

Smith, D. and McCullough, J.: 2001, *Alternative Code Implementation Strategies for States*, U.S. Department of Energy, Washington, DC, USA.

Sovacool, B.: 2006, *The Power Production Paradox: Revealing the Socio-Technical Impediments to Distributed Generation Technologies*, Virginia Polytechnic Institute and State University, Doctoral Dissertation, Blacksburg, VA, USA. See also: http://scholar.lib.vt.edu/theses/available/etd-04202006-172936/.

Speckler, S.: 2006, "Efficiency and Demand Response", presented at the 14 February, 2006 meeting of the National Association of Regulatory Utility Commissioners, Washington, DC, USA.

TecMarket Works Framework Team: 2004, *The California Evaluation Framework*, TecMarket Works, Oregon, WI, USA.

TecMarket Works Framework Team: 2006, *California Energy Efficiency Evaluation Protocols: Technical, Methodological and Reporting Requirements for Evaluation Professionals*, TecMarket Works, Oregon, WI, USA.

[USDOE] U.S. Department of Energy: 2000, *International Performance Measurement and Verification Protocol*. U.S. Department of Energy, Washington, DC, USA.

Vine, E.: 2003, "Opportunities for Promoting Energy Efficiency in Buildings as an Air Quality Compliance Approach", *Energy – The International Journal* **28**(4): 319–341.

Vine, E.: 2005, "An International Survey of the Energy Service Company (ESCO) Industry," *Energy Policy* **33**: 691–704.

Vine, E. and Kushler, M.: 1995, "The Reliability of DSM Impact Estimates", *Energy – The International Journal* **20**(12): 1171–1179.

Vine, E., Kushler, M., and York, D.: 2003, "Using Energy Efficiency to Help Address Electric System Reliability: An Initial Examination of 2001 Experience", *Energy – The International Journal* **28**(4): 303–317.

Vine, E. Rhee, C., and Lee, K.: 2006, "Measurement and Evaluation of Energy Efficiency Programs: California and South Korea", *Energy – The International Journal* **31**: 1100–1113.

York, D. and Kushler, M.: 2005, *Exploring the Relationship Between Demand Response and Energy Efficiency: A Review of Experience and Discussion of Key Issues*, American Council for an Energy Efficient Economy, Washington, DC, USA.

York, D. and Kushler, M.: 2006, "A Nationwide Assessment of Utility Sector Energy Efficiency Spending, Savings and Integration with Utility System Resource Acquisition," American Council for an Energy-Efficient Economy, *Proceedings of the 2006 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington, DC, USA.

CHAPTER 12

ENERGY MYTH ELEVEN – ENERGY R&D INVESTMENT TAKES DECADES TO REACH THE MARKET

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12.1. THE MYTH OF A MARKET SLOW TO ACT ON INNOVATIONS IN ENERGY R&D

An apocryphal story sometimes used to illustrate the "finding" that investments in energy R&D will be tremendously slow to move from laboratory to market is that of the microwave oven. In this version of the energy-research-to-market-pipeline, the microwave oven, first commercialized in the late 1960s and early 1970s is seen as a slowly developing consumer device from its roots in work on radar in World War II. In fact, the first commercial microwave oven, the *radar*-range, even borrowed its name from its genesis, over two decades before.

Carter et al. (1992) detail in an excellent work on the pace and efficiency of spin-off from military innovation to civilian product, however, that the microwave oven went through a number of significant post-military research and refinement stages to become a commercial product, and that while the *basic physics* of microwave heating of food relates to microwave imaging – radar – the *basic technology* is in fact highly distinct from the tracking of moving objects.

Nevertheless, the idea is often repeated that the innovation to market pathway is exceedingly slow in the energy field. For instance, Jae Edmonds (2001, p. 5) from the Pacific Northwest National Laboratory told senators:

> Given that it takes decades to go from "energy research" to the practical application of the research within some commercial "energy technology" and then perhaps another three to four decades before that technology is widely deployed throughout the global energy market, we will likely have to [combat global warming] with technologies that are already developed.

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 289–309

And Julie Fox Gorte and Tina Kaarsberg, (2001, p. 6) from the Northeast-Midwest Institute remark that research and development on energy technologies "usually takes years to pay off…the piper is paid five, ten, or more years in the future."

In many ways, nothing could be farther from the truth, and in fact, an analysis of the energy research to commercialization pathway shows it is quite efficient. The real culprit, as we will explore below, is much more the exceptionally small levels of support afforded energy research in the first place. This culture of *underinvestment*, particularly in energy, the largest component of both the United States and the global economy, is in itself shocking.

To lay to rest the myth of the broken pipeline one need look no further than the oft-cited "learning curve" (e.g., Duke and Kammen, 1999) that describes the relationship between cumulative production of a manufactured good, such as photovoltaics, and the labor inputs necessary per unit produced. During the 1970s, Boston Consulting Group (BCG) generalized the labor productivity learning curve to include all costs necessary to research, develop, produce and market a given product (Boston Consulting Group, 1972). That is, BCG argued that learning-by-doing occurs not only in the narrow sense of labor productivity improvements, but also in associated R&D, overhead, advertising and sales expenses.

These efficiency gains, in conjunction with the benefits from economies of scale, often yield cost reductions that can be characterized by an experience curve with the following form:

$$(12.1) \qquad \mathrm{UC} = aq^{-b}$$

Where UC = unit cost as a function of q = cumulative production, the parameter a = the cost of the first unit produced and b = the experience parameter (Argote and Epple, 1990). The underlying intuition for this exponential relationship is that there are diminishing returns to experience. Cost reductions are fast initially after production starts, but taper off as worker productivity becomes optimised, production is fully scaled up, incremental process improvements are made, and so on.

Extensive use has been made of the learning curve to provide a rough tracking of the production to cost relationship in the energy sector, and what we find (Figure 12.1) is that often for technology-specific underlying reasons, that a steady relationship between production and cost exists for a wider range of technologies. In fact, that relationship hovers around the widely accepted rule of thumb of a 20% cost decline for each doubling of cumulative production, a relationship seen broadly across industrial production, far beyond only the energy sector (Arrow, 1962). Figure 12.1 also includes the "exception that proves the rule" in the sense that one energy technology notably has not followed this 20% rule: nuclear power. In fact, for nuclear electricity generation, while each plant is based around a reactor core that is built in centralized manufacturing facilities – in the United States largely by Westinghouse and General Electric – the specific local geographic, political, and regulatory environments have been so different for the 104 plants constructed in the U.S., that the costs have been driven largely by these exogenous factors, not in the inherent economics of reactor core construction.

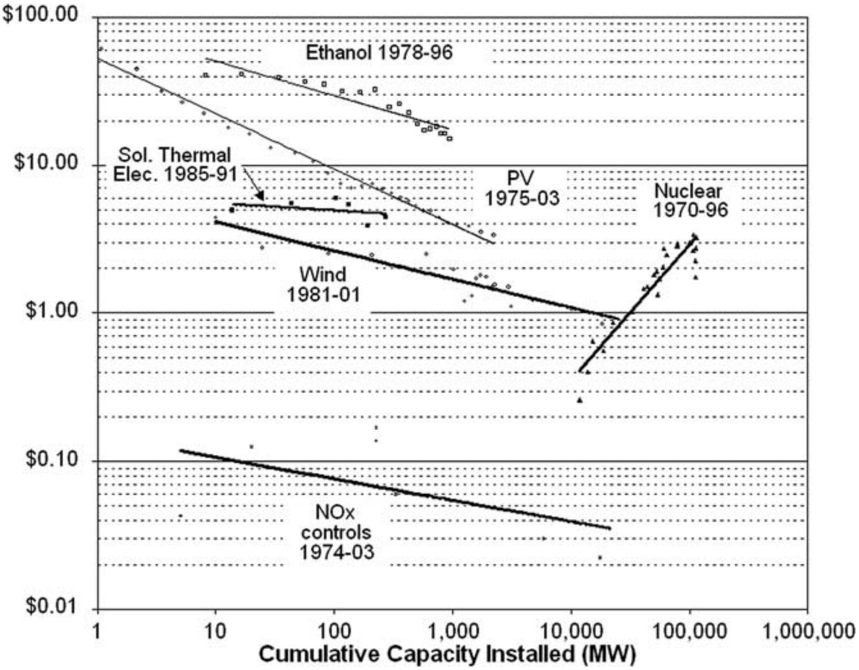


Figure 12.1. The 'learning curve' relationship between industrial production and cost (in 05$/W) for a range of energy technologies

What Figure 12.1 critically shows is that cost declines, often but certainly not always directly passed on to consumers, do generally follow directly from investment in innovation and then technology commercialization. The places where the energy R&D to market pathway is broken, however, are both more revealing

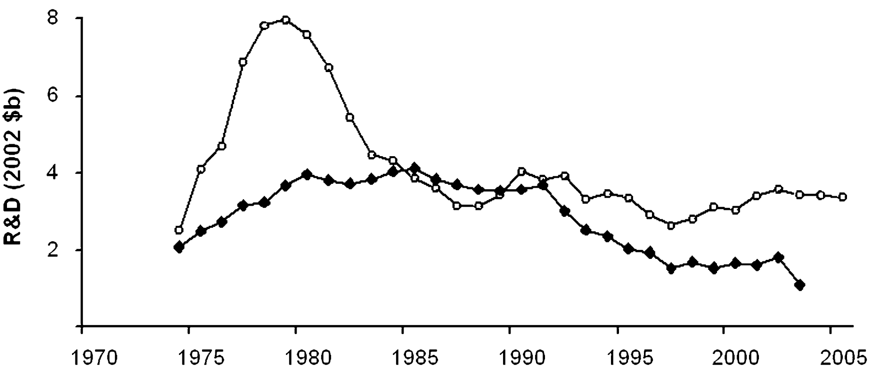


Figure 12.2. Energy R&D investment by public and private sectors

about how we manage the energy sector, and – thankfully – about the vehicles open to us today to address this crisis of innovation, commercialization, and of response to the looming crisis of global warming.

12.2. THE REAL CRISIS IN ENERGY RESEARCH INVESTMENT[1]

Investment in innovation in the U.S. energy sector is declining just as concerns about the environmental, geopolitical, and macroeconomic impacts of energy production and use are intensifying. With energy the largest industry on the planet, having sales of over $2 trillion annually, investment decisions in this sector have global consequences. The challenges of renewing the U.S. energy infrastructure to enhance economic and geopolitical security (Cheney, 2001) and prevent global climate change (Kennedy, 2004) are particularly acute, and depend on the improvement of existing technologies as well as the invention, development, and commercial adoption of emerging ones. Meeting these challenges also depends on the availability of tools to both effectively manage current energy technology investments, and to permit analysis of the most effective approaches and programs to significantly expand our resource of new energy technologies.

The federal government allocates over $100b annually for research and development (R&D) and considers it a vital "investment in the future" (Colwell, 2000). Estimates of the percent of overall economic growth that stems from innovation in science and technology are as high as 90% (Mansfield, 1972; Evenson et al., 1979; Griliches, 1987; Solow, 2000). The low investment and large challenges associated with the energy sector however, have led numerous expert groups to call for major new commitments to energy R&D. A 1997 report from the President's Committee of Advisors on Science and Technology and a 2004 report from the bipartisan National Commission on Energy Policy each recommended doubling federal R&D spending (PCAST, 1997; NCEP 2004). The importance of energy has led several groups to call for much larger commitments (Schock et al., 1999; Davis and Owens, 2003), some on the scale of the Apollo Project of the 1960s (Hendricks, 2004). These recommendations build on other studies in the 1990s that warned of low and declining investment in energy sector R&D (Dooley, 1998; Morgan and Tierney, 1998; Margolis and Kammen, 1999a, b). The scale of the energy economy, and the diversity of potentially critical low-carbon technologies to address climate change all argue for a set of policies to energize both the public and private sectors (Branscomb, 1993; Stokes, 1997), as well as strategies to catalyze productive interactions between them (Mowery, 1998a) in all stages of the innovation process.

These concerns however lie in stark contrast with recent funding developments. Although the Bush administration lists energy research as a "high-priority national need" (Marburger, 2004) and points to the Energy Policy Act passed in the summer of 2005 as evidence of action, the 2005 federal budget reduced energy R&D by 11 percent from 2004 (AAAS, 2004a). The American Association for the Advancement of Science (AAAS) projects a decline in federal energy R&D of 18 percent by 2009 (AAAS, 2004b). Meanwhile, and arguably most troubling, the lack of vision on energy is damaging the business environment for existing and start-up energy companies. Investments in energy R&D by U.S. companies fell by 50 percent between 1991 and 2003. This rapid decline is especially disturbing because commercial development is arguably the critical step to turn laboratory research into economically viable technologies and practices.[2] In either an era of declining energy budgets, or in a scenario where economic or environmental needs justify a significant increase in investments in energy research, quantitative assessment tools, such as those developed and utilized here, are needed.

To examine the trends in the research to innovation pipeline three inputs are needed: data on R&D investment data; indicators of innovative activity; and assessment of the feasibility of expanding to much larger levels of R&D. In previous work, we (Margolis and Kammen, 1999a, b; Kammen and Nemet, 2005) compiled time-series records of investments in U.S. energy R&D (Figure 12.2) (Jefferson, 2001; Meeks, 2004; Wolfe, 2004). Complementing the data on public sector expenditures, we developed and make available here a database of private sector R&D investments for fossil fuels, nuclear, renewables, and other energy technologies (http://ist-socrates.berkeley.edu/∼gnemet/RandD2006.html). In addition, we use U.S. patent classifications to evaluate the innovation resulting from R&D investment in five emerging energy technologies. We develop three methods for using patents to assess the effectiveness of this investment: patenting intensity, highly-cited patents, and citations per patent. Finally, we compile historical data on federal R&D programs and then assess the economic effects of a large energy R&D program relative to those.

12.3. DECLINING R&D INVESTMENT THROUGHOUT THE ENERGY SECTOR

The United States invests about $1 billion less in energy R&D today than it did a decade ago. This trend is remarkable, first because the levels in the mid-1990s had already been identified as dangerously low (Margolis and Kammen, 1999a, b), and second because, as our analysis indicates,[3] the decline is pervasive – across almost every energy technology category, in both the public and private sectors, and at multiple stages in the innovation process, investment has been either stagnant or declining (Figure 12.3). Moreover, the decline in investment in energy has occurred while overall U.S. R&D has grown by 6% per year, and federal R&D investments in health and defense have grown by 10–15% per year, respectively (Figure 12.4). As a result, the percentage of all U.S. R&D invested in the energy sector has declined from 10% in the 1980s to 2% today (Figure 12.5). Private sector investment activity is a key area for concern. While in the 1980s and 1990s, the private and public sectors each accounted for approximately half of the nation's investment in energy R&D, today the private sector makes up only 24%. The recent decline in private sector funding for energy R&D is particularly troubling because it has historically exhibited less volatility than public funding – private funding rose only moderately in the 1970s and was stable in the 1980s; periods during which federal funding

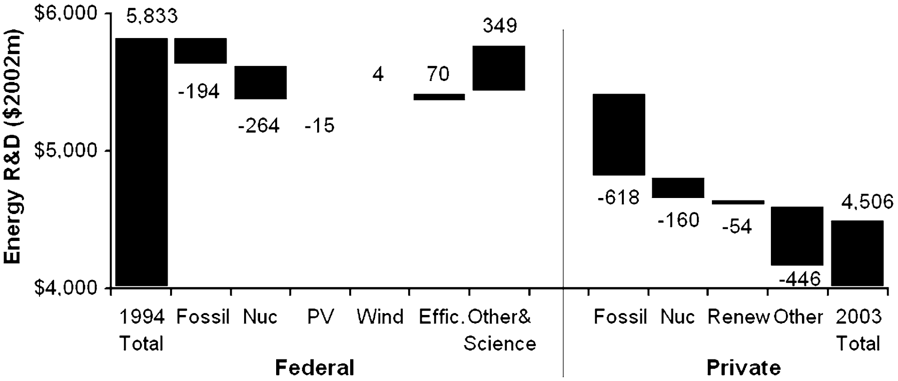


Figure 12.3. Changes in energy R&D investment by sector and technology 1994–2003

increased by a factor of three and then dropped by half. The lack of industry investment in each technology area strongly suggests that the public sector needs to play a role in not only increasing investment directly but also correcting the market and regulatory obstacles that discourage investment in new technology (Duke and Kammen, 1999). The reduced inventive activity in energy reaches back even to the earliest stages of the innovation process, in universities where fundamental research and training of new scientists occurs. For example, a recent study of federal support for university research raised concerns about funding for energy and the environment as they found that funding to universities is increasingly concentrated in the life sciences (Fossum et al., 2004).

A glimpse at the drivers behind investment trends in three segments of the energy economy indicates that a variety of mechanisms are at work. First, the market for

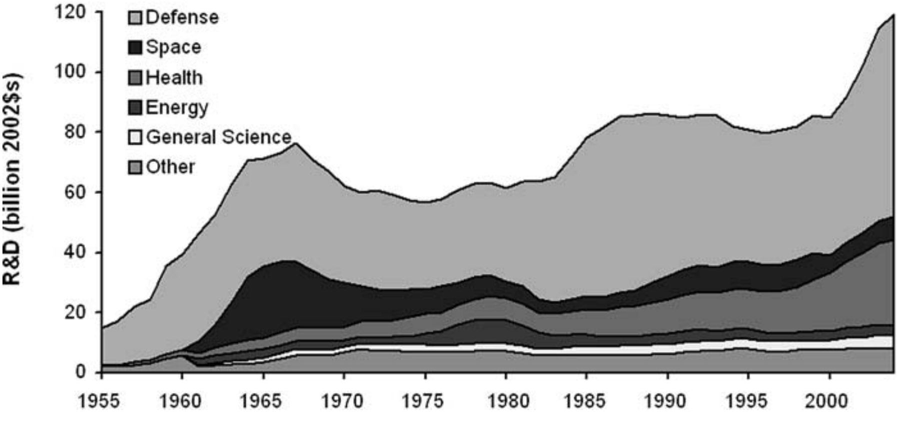


Figure 12.4. Federal R&D 1955 to 2004 annual level of R&D funding by federal agency

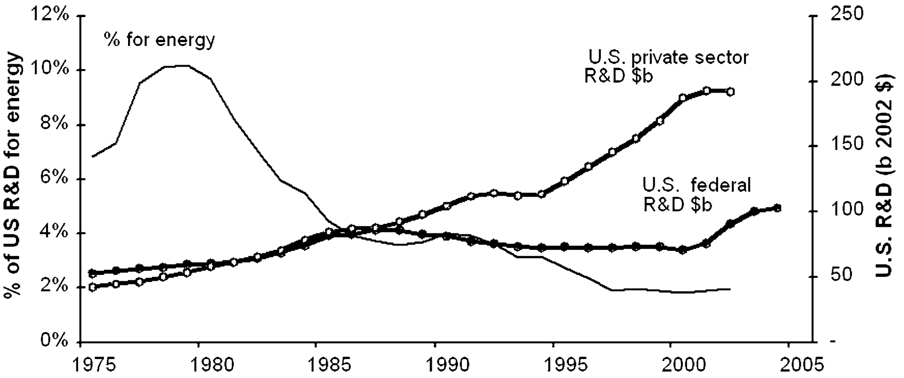


Figure 12.5. Total U.S. R&D and percentage devoted to energy

fossil fuel electricity generation has been growing by 2–3% per year and yet R&D has declined by half in the past 10 years, from $1.5b to $0.7b. In this case, the shift to a deregulated market has been an influential factor reducing incentives for collaboration, and generating persistent regulatory uncertainty. The industry research consortium, the Electric Power Research Institute (EPRI), has seen its budget decline by a factor of three. Rather than shifting their EPRI contributions to their own proprietary research programs, investor-owned utilities and equipment makers have reduced both their EPRI dues and their own research programs. The data on private sector fossil R&D validate prescient warnings in the mid-1990s (Dooley, 1998) about the effect of electricity sector deregulation on technology investment. Second, the decline in private sector nuclear R&D corresponds with diminishing expectations about the future construction of new plants. Over 90% of nuclear energy R&D is now federally funded. This lack of "demand pull" has persisted for so long that it even affects interest by the next generation nuclear workforce; enrolment in graduate-level nuclear engineering programs has declined by 26% in the last decade (Kammen, 2003). Recent interest in new nuclear construction has so far not translated into renewed private sector technology investment. Third, policy intermittency and uncertainty plays a role in discouraging R&D investments in the solar and wind energy sectors which have been growing by 20–35% per year for more than a decade. Improvements in technology have made wind power competitive with natural gas (Jacobson and Master, 2001) and have helped the global photovoltaic industry to expand by 50% in 2004 (Maycock, 2005). Yet, investment by large companies in developing these rapidly expanding technologies has actually declined. By contrast, European and Japanese firms are investing and growing market share in this rapidly growing sector making the United States increasingly an importer of renewables technology.

Venture capital investment in energy provides a potentially promising exception to the trends in private and public R&D. Energy investments funded by venture capital firms in the United States exceeded one billion dollars in 2000, and despite their subsequent cyclical decline to $520m in 2004, are still of the same scale as private R&D by large companies (Figure 12.6) (Prudencio, 2005). Recent announcements, such as California's plan to devote up to $450 million of its public pension fund investments to environmental technology companies and Pacific Gas and Electric's $30m California Clean Energy Fund for funding new ventures suggest that a new investment cycle may be starting (Angelides, 2004). The emergence of this new funding mechanism is especially important because studies have found that in general, venture capital investment is 3–4 times more effective than R&D at stimulating patenting (Kortum and Lerner, 2000). While it does not offset the declining investment by the federal government and large companies, the venture capital sector is now a significant component of the U.S. energy innovation system, raising the importance of monitoring its activity level, composition of portfolio firms, and effectiveness in bringing nascent technologies to the commercial market.

Finally, the drugs and biotechnology industry provides a revealing contrast to the trends seen in energy. Innovation in that sector has been broad, rapid and consistent. The 5,000 firms in the industry signed 10,000 technology agreements during the 1990s, and the sector added over 100,000 new jobs in the last 15 years (Cortwright and Meyer, 2002). Expectations of future benefits are high – the typical biotech firm spends more on R&D ($8.4 million) than it receives in revenues ($2.5 million), with the difference generally funded by larger firms and venture capital (PriceWaterhouseCoopers, 2001). Although energy R&D exceeded that of the biotechnology industry 20 years ago, today R&D investment by biotechnology firms is an order of magnitude larger than that of energy firms (Figure 12.7). In the mid-1980s, U.S. companies in the energy sector were investing more in R&D ($4.0 billion) than were drug and biotechnology firms ($3.4 billion), but by 2000, drug and biotech companies had increased their investment by almost a factor of 4–$13 billion. Meanwhile, energy companies had cut their investments by more than half to $1.6 billion. From 1980 to 2000, the energy sector invested $64 billion in R&D while the drug and biotech sector invested $173 billion. Today, total private sector

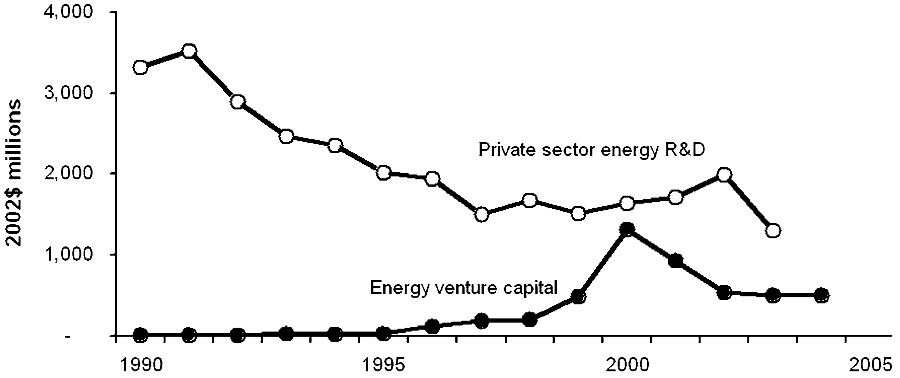


Figure 12.6. U.S. Venture capital investments in energy and private sector energy R&D

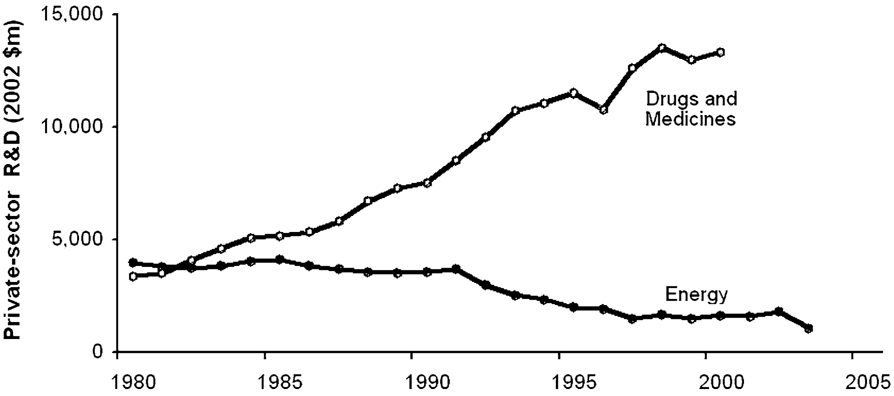


Figure 12.7. Private-sector R&D investment: energy vs. drugs and medicines

energy R&D is less than the R&D budgets of individual biotech companies such as Amgen and Genentech.

12.4. REDUCTIONS IN PATENTING INTENSITY

Divergence in investment levels between the energy and other sectors of the economy is only one of several indicators of under-performance in the energy economy. In this section we present results of three methods developed to assess patenting activity, which earlier work has found to provide an indication of the outcomes of the innovation process (Griliches, 1990).

First, we use records of successful U.S. patent applications as a proxy for the intensity of inventive activity and find strong correlations between public R&D and patenting across a variety of energy technologies (Figure 12.8)[4]. Since the early-1980s all three indicators – public sector R&D, private sector R&D, and patenting – have exhibited consistently negative trends.[5] Public R&D and patenting are highly correlated for wind, PV, fuel cells, and nuclear fusion. Nuclear fission is the one category that is not well correlated to R&D. Comparing patenting against private sector R&D for the more aggregated technology categories also reveals concurrent negative trends.[6] The long-term decline in patenting across technology categories and their correlation with R&D funding levels provide further evidence that the technical improvements upon which performance-improving and cost-reducing innovations are based are occurring with decreasing frequency.

Second, in the same way that studies measure scientific importance using journal citations (May 1997), patent citation data can be used to identify "high-value" patents (Harhoff et al., 1999). For each patent we identify the number of times it is cited by subsequent patents using the NBER Patent Citations Datafile (Hall et al., 2001). For each year and technology category, we calculate the probability of a patent being cited by recording the number of patents in that technology category in the next 15 years. We then calculate the adjusted patent citations for each year using a base year. "High-value" patents are those that received twice as many citations as the average patent in that technology category. Between 5 and 10% of the patents fell under our definition of high-value. The Department of Energy accounts for a large fraction of the most highly cited patents, with a direct interest in 24% (6 of the 25) of the most frequently referenced U.S. energy

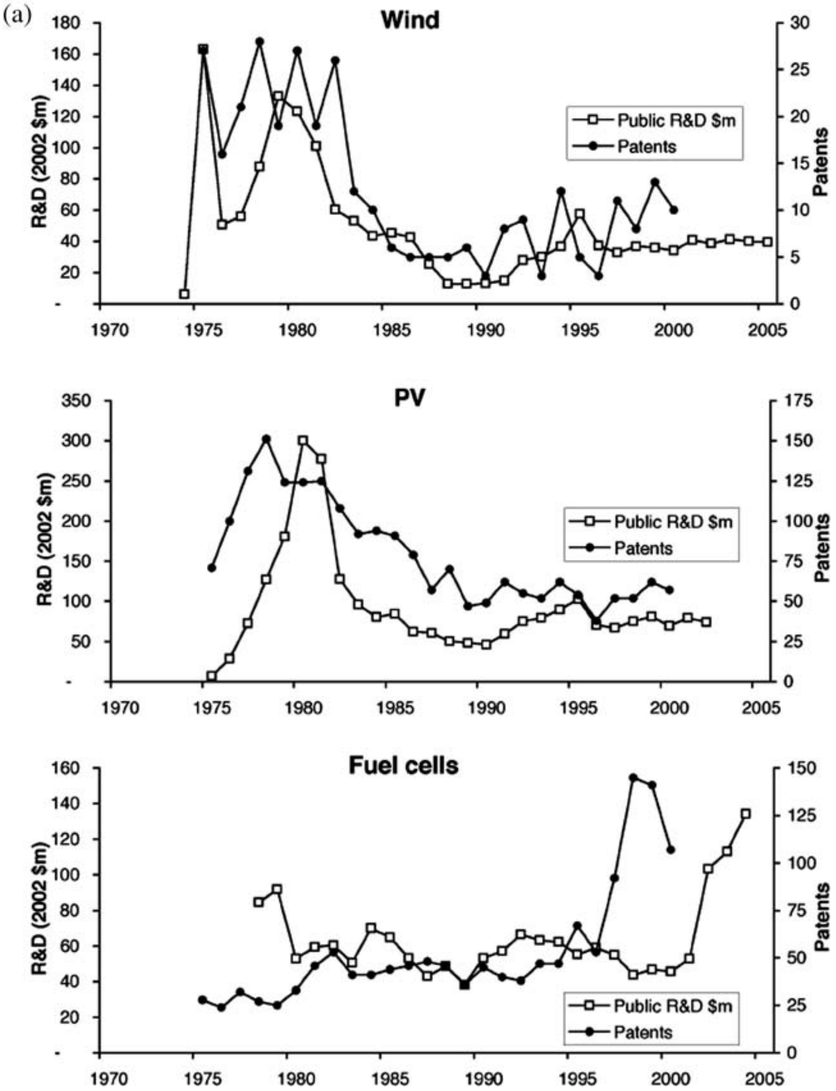


Figure 12.8. (Continued)

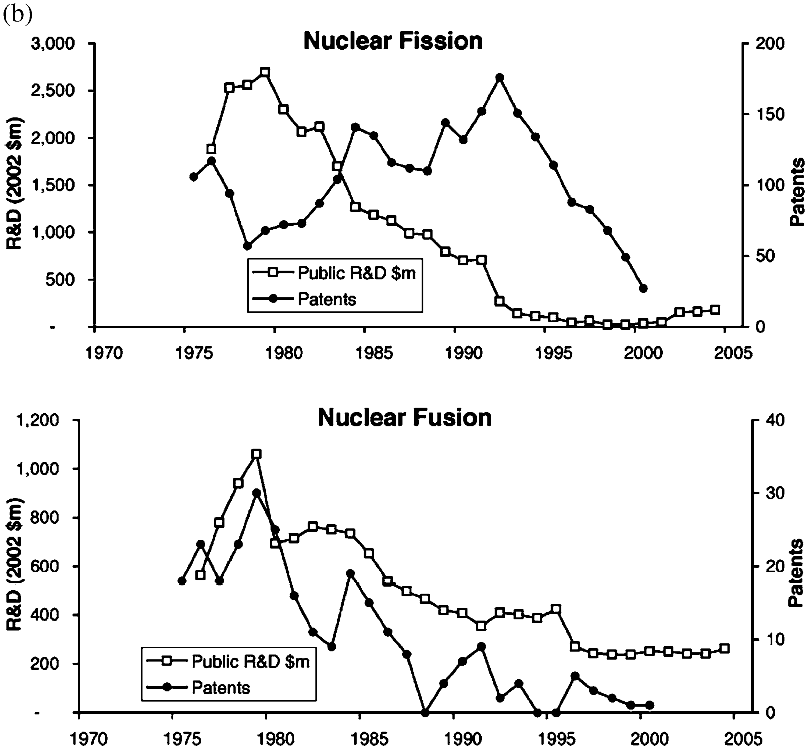


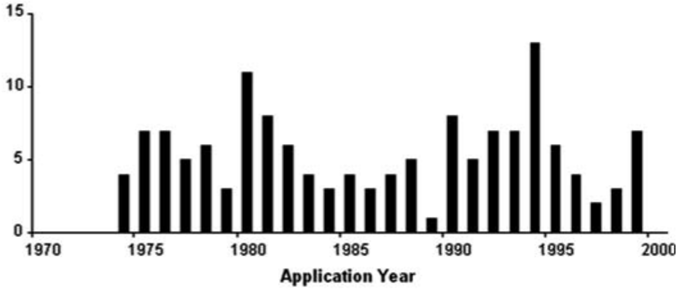
Figure 12.8. Patenting and federal R&D (a) Wind, PV, and Fuel Cells; (b) Nuclear Fission and Fusion

patents, while only associated with 7% of total U.S. energy patents. In the energy sector, valuable patents do not occur randomly – they cluster in specific periods of productive innovation (Figure 12.9).[7] The drivers behind these clusters of valuable patents include R&D investment, growth in demand, and exploitation of technical opportunities. These clusters both reflect successful innovations, productive public policies, and mark opportunities to further energize emerging technologies and industries.

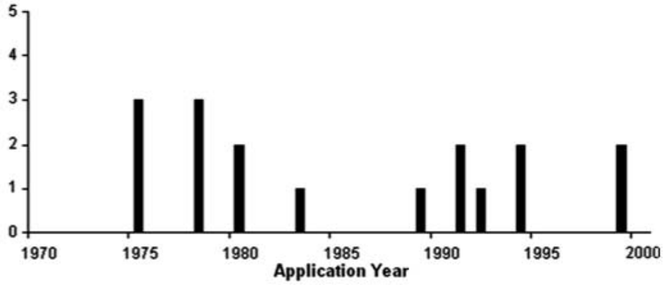
Third, patent citations can be used to measure both the return on R&D investment and the health of the technology commercialization process, as patents from government research provide the basis for subsequent patents related to technology development and marketable products. The difference between the U.S. federal energy patent portfolio and all other U.S. patents is striking, with energy patents earning on average only 68 percent as many citations as the overall U.S. average from 1970 to 1997 (Figure 12.10). This lack of development of government-sponsored inventions should not be surprising given the declining emphasis on innovation among private energy companies.

In contrast to the rest of the energy sector, investment and innovation in fuel cells have grown. Despite a 17% drop in federal funding, patenting activity intensified

a. Photovoltaics



b. Wind



c. Fuel cells

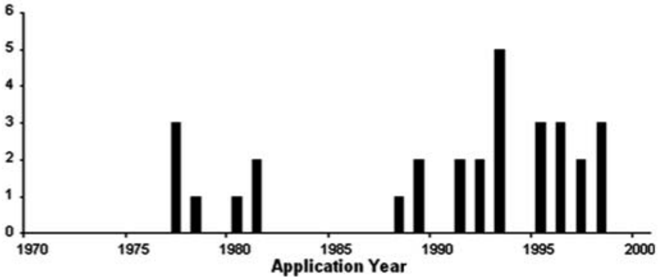


Figure 12.9. Highly cited patents

by nearly an order of magnitude, from 47 in 1994 to 349 in 2001. Trends in patenting and the stock prices of the major firms in the industry reveal a strong correlation between access to capital and the rate of innovation (Figure 12.11). The relationship between fuel cell company stock prices and patenting is stronger than that between patenting and public R&D. The five firms shown account for 24 percent of patents from 1999 to 2004. Almost 300 firms received fuel cell patents between 1999–2004, reflecting participation both by small and large firms. This combination of increasing investment and innovation is unique within the energy

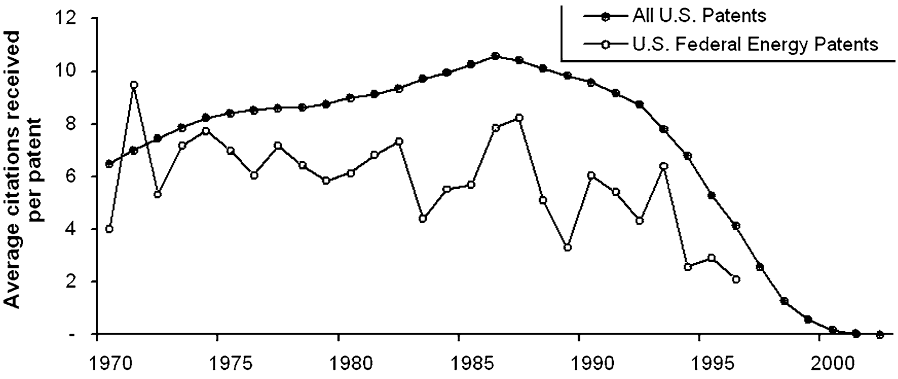


Figure 12.10. Average patent citations received per patent granted

sector. While investments have decreased as venture funding overall has receded since the late 1990s, the rapid innovation in this period industry has provided a large new stock of knowledge on which new designs, new products, and cost-reducing improvements can build. The industry structure even resembles that of the biotechnology industry. A large number of entrepreneurial firms and a few large firms collaborate through partnerships and intellectual property licensing to develop this earlier stage technology (Mowery, 1998b). The federal government, therefore, need not be the only driver of innovation in the energy sector if private sector mechanisms and business opportunities are robust.

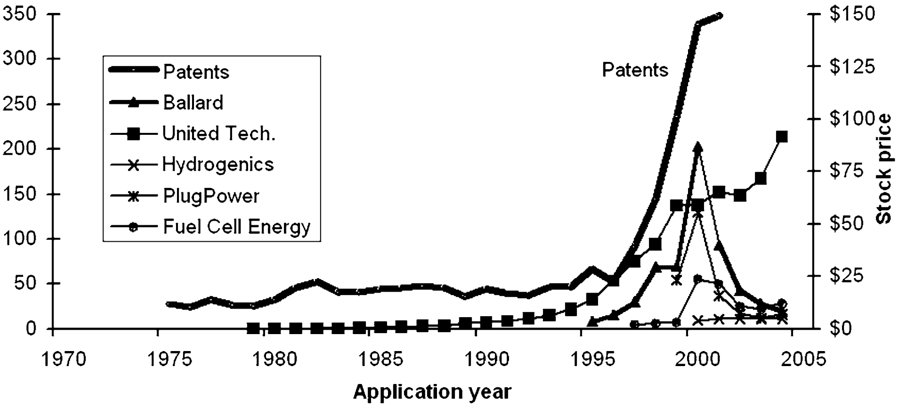


Figure 12.11. Fuel cell patenting and stock prices

12.5. COULD ENERGY R&D BE DRAMATICALLY INCREASED?

In light of this record, how feasible would it be to raise investment to levels commensurate with the energy-related challenges we face? Here we rely on earlier work to arrive at a range of plausible scenarios for optimal levels of energy R&D and then gauge the feasibility of such a project using historical data.

Calls for major new commitments to energy R&D have become common – while both the PCAST study of 1997 and the 2004 NCEP report recommend doubling federal energy R&D, others have found that larger increases are warranted. Davis and Owens, (2003) found that the option value of energy R&D justifies increasing spending to four times the present level. Schock et al. (1999) valued energy R&D by providing estimates of the insurance needed against oil price shocks, electricity supply disruptions, local air pollution, and climate change. By estimating the magnitude of the risks in each area and the probabilities of energy R&D programs to reduce them, they found that increasing energy R&D by a factor of four would be a "conservative" estimate of its insurance value. We note that this estimate assumes a mean climate stabilization target of between 650 and 750 ppm CO_2 and incorporates a 35% probability that no stabilization at all will be needed. A recalculation of their model to target the 560-ppm atmospheric level, scenario A1T ("rapid technological change") of the Intergovernmental Panel on Climate Change (Nakicenovic et al., 2000), increases the optimal R&D investment in energy R&D from \$17 to \$27 billion, 6 to 9 times the current level of investment. Uncertainty in the optimal level is indeed large. To incorporate the range of these estimates, we develop two scenarios for scaling up energy R&D, one for five times the current level and one for ten times.

The performance of previous large-scale R&D programs provides a useful test of the viability of carrying out an energy "Apollo" or "Manhattan" project, as these ventures are often termed. We find that a 5- to 10-fold increase in spending from current levels is not a "pie in the sky" proposal; in fact it is consistent with the growth seen in several previous federal programs, each of which took place in response to clearly articulated national needs. Past experience indicates that this investment would be repaid several times over in technological innovations, business opportunities, and job growth, beyond the already worthy goal of developing a low-carbon economy. We assembled data and reviewed spending patterns of the six previous major federal R&D initiatives since 1940 (Table 12.1) and use five measures to compare them to scenarios of increasing energy R&D by factors of five and ten. For each of these eight programs we calculate a "baseline" level of spending. The difference between the actual spending and the baseline during the program we call extra program spending. We compare the energy scenarios to the other initiatives using five measures that address both the peak year and the full duration of the program. A 10x expanded energy investment scenario is within the range of the previous programs in all but one measure, where it exceeds by 10%. A 5× energy scenario is in the lower half of the range for each measure. Figure 12.12 shows the scenarios (as circles) plotted against the range of previous

Table 12.1. Comparison of Energy R&D Scenarios and Major Federal Government R&D Initiatives (2002 $b)

			Peak Year ($ Billions)		Program Duration ($ Billions)		
Program	Sector	Years	Spending	Increase	Spending	Extra Spending	Factor Increase
Manhattan Project	Defense	1940–1945	$10.0	$20.0	$25.0	$25.0	n/a
Apollo Program	Space	1963–1972	$23.8	$19.8	$184.6	$127.4	3.2
Project Independence	Energy	1975–1982	$7.8	$5.3	$49.9	$25.6	2.1
Reagan Defence	Defense	1981–1989	$58.4	$27.6	$445.1	$100.3	1.3
Doubling NIH	Health	1999–2004	$28.4	$13.3	$138.3	$32.6	1.3
War on Terror	Defense	2002–2004	$67.7	$19.5	$187.1	$29.6	1.2
5x energy scenario	*Energy*	*2005–2015*	*$17.1*	*$13.7*	*$96.8*	*$47.9*	*2.0*
10x energy scenario	*Energy*	*2005–2015*	*$34.0*	*$30.6*	*$154.3*	*$105.4*	*3.2*

programs. While expanding energy R&D to five or ten times today's level would be a significant initiative, the fiscal magnitude of such a program is well within the range of previous programs, each of which has produced demonstrable economic benefits beyond the direct program objectives.

A critical role for public sector investment has always been to energize and facilitate private sector activity. In fact, increasing energy R&D investment in the private sector by a factor of five or ten would not even rival what is seen in other high-technology sectors. From 1988 to 2003 the U.S. energy industry invested only 0.23% of its revenues in R&D. This compares to the period 1975–1987 when private sector R&D averaged 1.1%, peaking at 1.4% in 1978. Overall R&D in the US economy was 2.6% of GDP over that time and has been increasing. High-tech industries such as pharmaceuticals, software, and computers routinely invest between 5 and 15% of revenues in R&D (MIT, 2002). An order of magnitude increase in R&D investments by the energy industry would still leave the energy sector's R&D

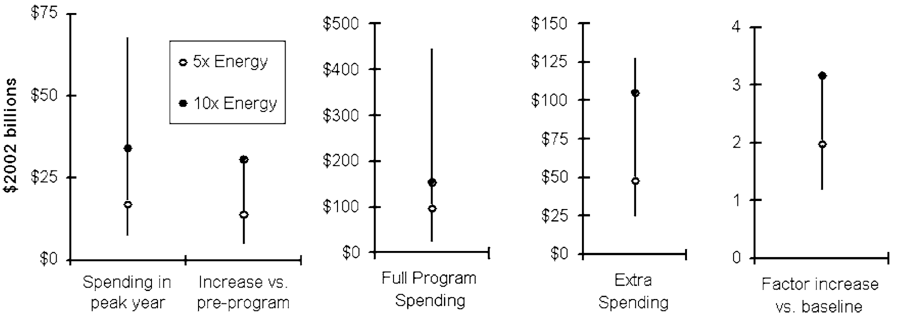


Figure 12.12. Energy R&D scenarios plotted against the range of previous programs

intensity below the average of 2.6% for U. S. industry as a whole (BEA, 2004; Wolfe, 2004). If the electric power industry alone were to devote 2% of revenue to R&D for the next decade, the resulting $50 billion would exceed cumulative energy R&D invested since the 1970s, yet would be smaller than cumulative profits of $168 billion from 1994 to 2003 (Kuhn, 2004) and would be dwarfed by the $1.7 trillion forecast to be spent on new equipment and upgrades in the North American power sector from 2001 to 2030 (Birol, 2003). The confluence of this upcoming capital investment and a federal programmatic initiative and commitment would enable new capacity to make full use of the technologies developed in a research program and would provide opportunities for incorporating market feedback and stimulating learning effects.[8] Given recent investment declines in the private sector, creating an environment in which firms begin to invest at these levels will be an important policy challenge.

We also examined the thesis that these large programs "crowd out" other research and using the data described in this study, found that the evidence for this contention is weak or nonexistent. In fact, large government R&D initiatives were associated with higher levels of both private sector R&D and R&D in other federal programs. The economy-wide effects of such major R&D programs could arguably be either negative or positive. The positive macro effects of R&D accrue from two types of "spillovers:" firms do not capture the full value of their innovations (Jones and Williams, 1998) and indirect benefits emerge, such as the 10:1 benefit ratio of the Apollo program (Apollo-Alliance, 2004) and the numerous unanticipated applications of energy R&D to product improvements in other fields (e.g., Brown and Wilson, 1998). Assuming that the value of the direct outcomes of an R&D program exceed investment, the main negative consequence of large R&D programs is that they may crowd out R&D in other sectors by limiting these other sectors' access to funding and scientific personnel.[9] The R&D data described above can be used to develop a simple model relating these six major federal R&D programs to R&D spending in other areas, both in the public and private sectors. We test two aspects of the crowding-out hypothesis: First, whether large federal programs are associated with reduced spending in other federal R&D, and second, whether these programs lead to lower spending in private sector R&D. In a model of spending on *other federal R&D activities*, we controlled for GDP and found that the coefficient for the targeted R&D effort is small, positive, and significant.[10] We found a similar result in a model explaining *private R&D*.[11] Our data on private R&D extend only to 1985, and therefore do not go back far enough to test for significant results. However, a glance at R&D trends in both energy and biotech show that private investment *rose* during periods of large government R&D increases. One interpretation of these results is that the signal of commitment that a large government initiative sends to private investors outweighs any crowding-out effects associated with competition over funding or retention of scientists and engineers. Another is that in these long-term programs, the stock of scientists and engineers is not fixed. Just as the dearth of activity in the nuclear sector has led to decreased enrolment in graduate programs, a large long-term program with a signal of commitment from public leaders can increase the numbers of trained professionals within a few years. These results suggest that the crowding-out effect of previous programs was weak, if it existed at all. Indeed our results indicate the opposite of a crowding-out effect: large government R&D initiatives are associated with higher levels of both private sector R&D and R&D in other federal programs.[12]

12.6. CONCLUSION

First and foremost, we find that the myth that research and development in energy technologies takes years to reach the marketplace is patently false. Instead, innovation and commercial activity follows R&D activity and intensity to a remarkable degree in the energy sector, particularly when one considers that it often takes a great deal of capital to bring a new energy innovation to market. This *effective* R&D pipeline is, in fact, all the more remarkable given how little is invested in this sector relative to its national and global importance. It is in this second area, of the overall attention that energy R&D receives, that we find the real problem.

The decline in energy R&D and innovative activity seen over the past three decades is pervasive and, apparently a continuing trend. While government funding is essential in supporting early stage technologies and sending signals to the market, evidence of private sector investment is an important indicator of expectations about technological possibilities and market potential. The dramatic declines in private sector investment are thus particularly concerning if we are to employ an innovation-based strategy to confront the major energy-related challenges society now faces. R&D alone is not sufficient to bring the new energy technologies we will require to widespread adoption. However, the correlations we report demonstrate that R&D is an essential component of a broad innovation-based energy strategy that includes transforming markets and reducing barriers to the commercialization and diffusion of nascent technologies. The evidence we see from past programs indicates that we can effectively scale up energy R&D, without hurting innovation in other sectors of the economy. At the same time, such a large and important project will require the development of additional ways of assessing returns on investments to inform the allocation of support across technologies, sectors, and the multiple stages of the innovation process.

ACKNOWLEDGEMENTS

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NOTES

[1] This section draws heavily on Nemet and Kammen (2007).

[2] See the "valley of death" discussion in PCAST, 1997.

[3] We disaggregate energy R&D into its four major components: fossil fuels, nuclear power, renewables and energy efficiency, and other energy technologies (such as environmental programs). While public

spending can be disaggregated into more precise technological categories, this level is used to provide consistent comparisons between the private and public sectors. For individual years in which firm-level data is kept confidential, averages of adjacent years are used.

[4] Patents data were downloaded from USPTO, 2004.

[5] From 1980 to 2003, public R&D declined by 54%, private R&D by 67%, and patenting by 47%.

[6] While the general correlation holds here as well, the abbreviated time-series (1985–2002) and the constant negative trend reduce the significance of the results.

[7] Analysis based on the citation weighting methodology of Dahlin et al, 2004.

[8] It is important to note that this analysis does not suggest that energy utilities should necessarily be asked or expected to make this investment without strong assurance that public sector investment will itself increase, but more critically that these investments will be facilitated by regulation and incentives that reward research into clean energy technologies and practices.

[9] Economic analyses of the value of research have found that costs of policies are highly sensitive to the presence of R&D crowding-out effects, the actual extent of crowding remains subject to widely varying assumptions. See Goulder and Mathal, 2000 and Popp, 2004.

[10] Regression Model for Other Federal R&D:

$$\begin{array}{l} \log(\text{Other-fed-RD}) = \underset{(0.06)}{3.35} + \underset{(0.01)}{0.03^{*}}\log(\text{program-RD}) + \underset{(0.03)}{0.43^{*}}\log(\text{GDP}) + e \\ n = 31 \quad r^2 = 0.87 \ {}^{*}\text{significant at 95\%level} \end{array}$$

[11] Regression Model for Private R&D:

$$\begin{array}{l} \text{Private-RD} = \underset{(5.22)}{-87.2} + \underset{(2.31)}{7.40^{*}}(\text{program-dummy}) + \underset{(0.06)}{25.8^{*}}\text{GDP} + e \\ n = 28 \quad r^2 = 0.99 \ {}^{*}\text{significant at 95\%level} \end{array}$$

[12] In current work in progress we are collecting data to explore an alternative measure by looking at the effects on private R&D investment within the sector for which the government is initiating a large program.

REFERENCES

[AAAS] American Association for the Advancement of Science: 2004a, “Nondefense R&D Budgets Face Major Squeeze.” *Issues in Science and Technology* 21(1): 17–19.

[AAAS] American Association for the Advancement of Science: 2004b, “Analysis of the Outyear Projections for R&D in the FY 2005 Budget,” *AAAS Report XXIX: Research and Development FY 2005*, AAAS, Washington, DC, [online] http://www.aaas.org/spp/rd/rd05main.htm, accessed July 2006.

Angelides, P.: 2004, “State Treasurer Phil Angelides Launches ‘Green Wave’ Environmental Investment Initiative,” Office of the State Treasurer of California, Sacremento, CA.

Apollo-Alliance: 2004, *The Apollo Jobs Report: Good Jobs and Energy Independence, New Energy for America*, The Apollo Alliance, [online]. http://www.apolloalliance.org/docUploads/ApolloReport.pdf, accessed July 2006

Argote, L. and Epple, D.: 1990, “Learning Curves in Manufacturing,” *Science* 247: 920–924.

Arrow, K.J.: 1962, “The Economic Implications of Learning by Doing,” *Review of Economic Studies* 29: 166–170.

[BEA] Bureau of Economic Analysis: 2004, *Gross Domestic Product (GDP) by Industry*, Bureau of Economic Analysis, Washington, DC.

Birol, F.: 2003, *World Energy Investment Outlook*, International Energy Agency, Paris.

Boston Consulting Group: 1972, *Perspectives on Experience*, Boston Consulting Group, Inc., Boston, MA.

Branscomb, L.M.: 1993, *Empowering Technology: Implementing a U.S. Strategy*, The MIT Press, Cambridge, MA.

Brown, M.A. and Wilson, C.R.: 1993, "R&D Spinoffs: Serendipity vs. A Managed Process," *Journal of Technology Transfer* 18 (3–4): 5–15.

Carter, Ashton B., Alic, John, Branscomb, Lewis, Brooks, Harvey, and Epstein, Gerald: 1992, *Beyond Spinoff: Military and Commercial Technologies in a Changing World*, Harvard Business School Press, Cambridge, MA.

Cheney, D.: 2001, "National Energy Policy," National Energy Policy Development Group, Office of the Vice President, Washington, DC.

Colwell, R.R.: 2000, *America's Investment in the Future*, National Science Foundation, Washington, DC.

Cortwright, J. and Meyer, H.: 2002, *Signs of Life: The Growth of Biotechnology Centers in the U.S.*, Brookings, Washington, DC.

Dahlin, K., Taylor, M., and Fichman, M: 2004, "Today's Edisons or Weekend Hobbyists: Technical Merit and Success of Inventions by Independent Inventors." *Research Policy* 33, 1167–1183.

Davis, G.A. and Owens, B.: 2003, "Optimizing the Level of Renewable Electric R&D Expenditures using Real Options Analysis," *Energy Policy* 31: 1589–1608.

Dooley, J. J.: 1998, "Unintended Consequences: Energy R&D in a Deregulated Energy Market." *Energy Policy* 26(7): 547–555.

Duke, R.D. and Kammen, D.M.: 1999, "The Economics of Energy Market Transformation Initiatives." *The Energy Journal* 20: 15–64.

Edmonds, Jae: 2001, "The Science of Climate Change." *Testimony Before the Senate Energy and Natural Resources Committee*, [online] http://www.pnl.gov/news/testimony/climate62801edmonds.stm, accessed July 2006.

Evenson, R.E., Waggoner, P.E., and Ruttan, V.W.: 1979, "Economic Benefits from Research: An Example from Agriculture." *Science* 205: 1101–1107.

Fossum, D., Painter, L.S., Eiseman, E., Ettedgui, E., and Adamson, D.: 2004, *Vital Assets: Federal Investment in Research and Development at the Nation's Universities and Colleges*, RAND Santa Monica, CA, [online] http://www.rand.org/pubs/monograph_reports/2005/MR1824.pdf, accessed July 2006.

Gorte, Julie Fox and Kaarsberg, Tina: 2001, *Electricity Restructuring, Innovation, and Efficiency*, [online] http://www.nemw.org/ER_ERIE.htm, accessed July 2006.

Goulder, L.H. and Mathai, K.: 2000, "Optimal CO_2 Abatement in the Presence of Induced Technological Change," *Journal of Environmental Economics and Management* 38: 1–38.

Griliches, Z.: 1987, "R&D and Productivity: Measurement Issues and Econometric Results." *Science* 237(4810): 31–35.

Griliches, Z.: 1990, "Patent Statistics as Economic Indicators: A Survey," *Journal of Economics Literature* 28: 1661–1707.

Hall, B.H., Jaffem A.B., and Trajtenberg, M.: 2001, "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools" NBER Working Paper 8498, [online] http://papers.nber.org/papers/w8498.pdf, accessed July 2006.

Harhoff, D., Narin, F., Scherer, F.M., and Vopel, K.: 1999, "Citation Frequency and the Value of Patented Inventions," *The Review of Economics and Statistics* 81(3): 511–515.

Hendricks, B.: 2004, "Testimony to the House Committee on Resources Oversight Hearing on Energy Supply and the American Consumer, Executive Director, Apollo Alliance," U.S. House of Representatives. Washington, DC.

Jacobson, M.Z. and Master, G.M.: 2001, "Energy: Exploiting Wind Versus Coal," *Science* 293(5534): 1438.

Jefferson, M.: 2001, *Energy Technologies for the 21st Century*, World Energy Council, London.

Jones, C.I. and Williams, J.C.: 1998, "Measuring the Social Return to R&D," *The Quarterly Journal of Economics*: 1119–1135.

Kammen, D.M.: 2003, *The Future of University Nuclear Science and Engineering Programs*, U.S. House of Representatives Science Committee, sub-committee on Energy, Washington, DC.

Kammen, D.M. and Nemet, G.: 2005, “Reversing the Incredible Shrinking Energy R&D Budget,” *Issues in Science & Technology*, Fall: 84–88.

Kennedy, D.: 2004, “Climate Change and Climate Science.” *Science* 304(5677): 1565.

Kortum, S. and Lerner, J.: 2000, “Does Venture Capital Spur Innovation?” *Rand Journal of Economics* 31: 674–692.

Kuhn, T.: 2004, *Annual Report of the U.S. Shareholder-owned Electric Utility Industry*, Edison Electric Institute, Washington, DC.

Mansfield, E.: 1972, “Contribution of R&D to Economic Growth in the United States,” *Science* 175: 477–486.

Marburger, J.H.: 2004, “Science for the 21st Century,” Washington, DC, U.S. Office of Science and Technology Policy.

Margolis, R.M. and Kammen, D.M.: 1999a, “Evidence of Under-investment in Energy R&D in the United States and the Impact of Federal Policy,” *Energy Policy* 27: 575–584.

Margolis, R.M. and Kammen, D.M.: 1999b, “Underinvestment: The Energy R&D Challenge.” *Science* 285: 690–692.

May, R.M.: 1997, “The Scientific Wealth of Nations,” *Science* 275(5301): 793.

Maycock, P.D.: 2005, *PV Technology, Performance, Cost and Market Update, 1990–2005*, PV Energy Systems, Inc., New York, NY.

Meeks, R.L.: 2004, “Federal R&D Funding by Budget Function: Fiscal Years 2003–05,” National Science Foundation, Division of Science Resources Statistics, Arlington, VA.

MIT: 2002, “R&D Scorecard 2002,” *Technology Review*, December.

Morgan, M.G. and Tierney, S.F.: 1998, “Research Support for the Power Industry,” *Issues in Science and Technology*, Fall, [online] http://www.issues.org/15.1/morgan.htm, accessed July 2006.

Mowery, D.C.: 1998a, “The Changing Structure of the U.S. National Innovation System: Implications for International Conflict and Cooperation in R&D Policy,” *Research Policy* 27: 639–654.

Mowery, D.C.: 1998b, “Collaborative R&D: How Effective Is It?” *Issues in Science and Technology* 15(1): 37–44.

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, Bert, Fenhann, Joergen, Gaffin, Stuart, Gregory, Kenneth, Grübler, Arnulf, Jung, Tae Yong, Kram, Tom, La Rovere, Emilio Lebre, Michaelis, Laurie, Mori, Shunsuke, Morita, Tsuneyuki, Pepper, William, Pitcher, Hugh, Price, Lynn, Riahi, Keywan, Roehrl, Alexander, Rogner, Hans-Holger, Sankovski, Alexei, Schlesinger, Michael, Shukla, Priyadarshi, Smith, Steven, Swart, Robert, van Rooijen, Sascha, Victor, Nadejda, and Dadi, Zhou: 2000, *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, Cambridge University Press, New York, NY, USA, [online] http://www.grida.no/climate/ipcc/emission/index.htm, accessed July 2006.

[NCEP] National Commission on Energy Policy: 2004, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America’s Energy Challenges*, The National Commission on Energy Policy, Washington, DC.

Nemet, G. and Kammen, D.M: 2007, “U.S. Energy Research and Development: Declining Investment, Increasing Need, and the Feasibility of Expansion,” *Energy Policy* 35(1): 746–755.

[PCAST] President’s Committee Of Advisors On Science And Technology: 1997, “Report to the President on Federal Energy Research and Development for the Challenges of the Twenty-First Century,” [online] http://www.ostp.gov/Energy/index.html, accessed July 2006.

Popp, D.: 2004, “ENTICE-BR: The Effects of Backstop Technology R&D on Climate Policy Models,” NBER, Cambridge, MA, [online] http://papers.nber.org/papers/w10285.pdf, accessed July 2006.

PriceWaterhouseCoopers: 2001, *Money Tree Survey*, [online] http://www.PriceWaterhouseCoopers.com, accessed July 2006.

Prudencio, R.: 2005, “Nth Power 2003 Energy Venture Capital Study,” Nth Power LLC, San Francisco, CA.

Schock, R. N., Fulkerson, W., Brown, Merwin L., San Martin, Robert L., Greene, David L., and Edmonds, Jae: 1999, “How much is Energy Research and Development Worth as Insurance?” *Annual Review of Energy and Environment* 24: 487–512.

Solow, R.M.: 2000, *Growth Theory: an Exposition*, Oxford University Press, Oxford.
Stokes, D E.: 1997, *Pasteur's Quadrant: Basic Science and Technological Innovation*, Brookings Institution Press, Washington, DC.
USPTO: 2004, US Patent Bibliographic Database, [online] www.uspto.gov/patft/, accessed July 2006.
Wolfe, R.M.: 2004, "Research and Development in Industry," National Science Foundation, Division of Science Resources Statistics, Arlington, VA.

CHAPTER 13

ENERGY MYTH TWELVE – CLIMATE POLICY WILL BANKRUPT THE U.S. ECONOMY

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A common argument for not taking action – or at least delaying action – on climate change is that the cost of action is too high. President Bush, for example, justified rejecting the Kyoto Protocol because of the expense, noting in a speech to the National Oceanic Atmospheric Administration (NOAA) that it would cost the United States $400 billion and 4.9 million jobs (Whitehouse, 2002). The American Council for Capital Formation (ACCF), an industry funded advocacy group, also often cites high cost, job losses, and overall – damaging economic consequences, as justification for rejecting any type of mandatory climate policy at the state or federal level (Thorning, 2006a–c). Repeating these same arguments over and over, it does not matter which policy is proposed – all are too expensive.

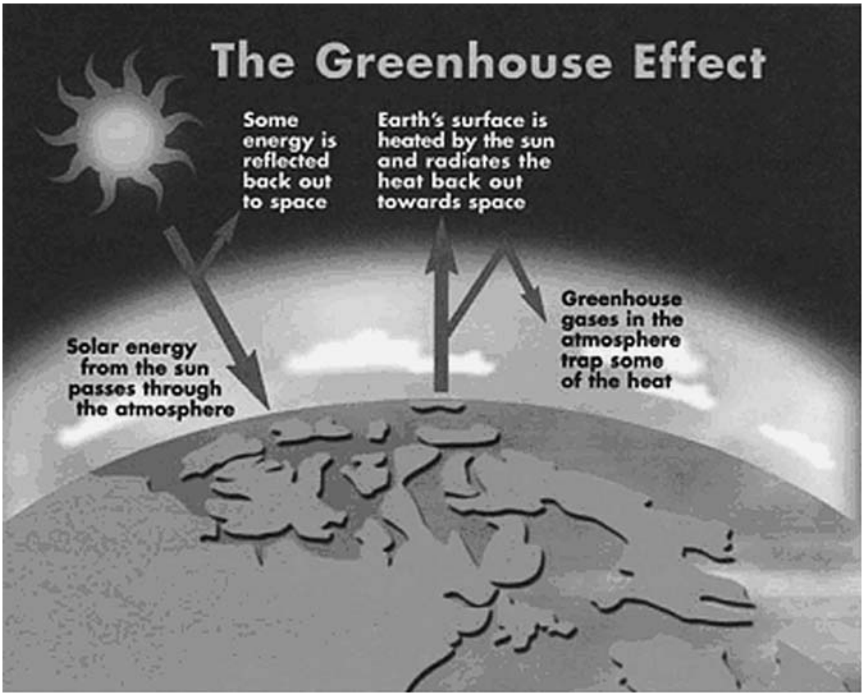
Economic models typically provide the foundation for these high cost projections but it is important to realize that a variety of models have been used to predict the implications of climate policy and not all suggest such devastating consequences. While models have much to offer the policy realm, their results are only as reliable as the assumptions, the data and the modeling structure allow. Unfortunately, many of the models which have looked at climate policy have been limited in scope, make draconian assumptions about our ability to change and lead to results suggesting that *any* effort is too costly. Furthermore, these models have typically done a poor job of accounting for the long-term benefits of taking action (i.e., avoiding the damages of climate change) and in many cases, these benefits are not even included – again lending support to the myth that we can't afford to take action on climate change. The truth, however, is that we can't afford to put it off. Putting off the date of enacting a mandatory program makes the problem associated with climate change larger, increases the costs that future generations must bear and increases the risk of irreversible climate damage that could devastate regional economies (see Box 13.1 for a simplified description of the greenhouse effect).

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 311–340.

The following pages address the myth that climate policy is too expensive by looking first at why the myth exists, where the high cost projections originate, and how the assumptions included in the models can lead to over-estimates of cost. We also look at the importance of policy design because the elements and flexibilities included are key to keeping costs low. While there will be a cost associated with climate change policy, changes need not happen all at once, and strategically applied, sensible policy will keep these costs at a minimum. Finally, the last part of this chapter talks about the costs of delaying mandatory policy. Taking action on climate change, if we do it right, will not bankrupt our economy but if we do nothing the costs of inaction could.

Box 13.1. Box The Greenhouse Effect

Most of the solar energy that reaches the earth is absorbed by the oceans and land masses and radiated back into the atmosphere in the form of heat or infrared radiation. Most of this infrared energy is absorbed and reradiated by atmospheric gases such as water vapor and carbon dioxide. This phenomenon, referred to as the greenhouse effect, serves to keep the earth some 33 °C (60 °F) warmer than it would otherwise be. As concentrations of gases that absorb and reradiate infrared energy (i.e., greenhouse gases) increase, the warming effect increases.



(*Source*: Environment Canada)

The result of this increase is that the earth is warming. Temperatures at the Earth's surface increased by an estimated 1.4 °F (0.8 °C) between 1900 and 2005. The past decade was the hottest of the past 150 years and perhaps the past millennium. The hottest 22 years on record have occurred since 1980, and 2005 was the hottest on record.

The growing scientific consensus is that this warming is largely the result of emissions of carbon dioxide and other greenhouse gases from human activities including industrial processes, fossil fuel combustion, and changes in land use, such as deforestation. Projections of future warming suggest a global increase of 2.5 °F (1.4 °C) to 10.4 °F (5.8 °C) by 2100, with warming in the United States expected to be even higher. In addition to warming, increases in sea level and changes in precipitation, including more frequent floods and droughts, are likely. These changes are referred to broadly as "climate change".

13.1. MYTH ORIGINS

A central tenet in evaluating any proposed regulation is that benefits should exceed costs. If not, then policy is deemed too expensive and unjustified. This proves to be a difficult standard for environmental regulations, since the benefits such regulations provide are often diffuse (impacting a wide scope of individuals), without specific market value, and may not materialize until the distant future. In contrast, costs (even if they are smaller) are more immediate, tangible (directly relevant to select industries), and certain. This issue is even more pronounced for climate policy because of its global scope, our lack of complete understanding of climate response, and the very long-term nature of some of the benefits from avoiding the most significant impacts of climate change. As such, it is relatively easy for those opposed to climate policy to make the case that (1) increased costs will impact our competitiveness vis-à-vis countries without such policies; (2) job losses will result; and more generally, (3) that costs are too high in comparison to the benefits. These arguments form the basis of the myth that climate policy is too expensive.

13.1.1 Competitiveness Impacts

With respect to the first two arguments that environmental policy will impact our national competitiveness and result in job losses – these claims are fundamentally tied to the level of cost imposed on the economy and on specific sectors. In the next section we explore this issue of the cost of policy in detail. Here, though, our objective is simply to point out that while this is a common argument applied to environmental policy, it is not conclusively supported by empirical analysis. Furthermore, while economists have looked at a variety of economic indicators such as plant location, industry imports and exports, foreign direct investment, trade constraints, and domestic resource endowments to determine the impact of environmental regulation on competitiveness, the exact nature of the impact is still unresolved.

A few notable studies have suggested that environmental regulation improves competitiveness. Michael Porter's research on this topic is often cited in support of this theory. According to Porter, environmental regulations force firms to fundamentally rethink their production processes which can stimulate innovation and lead to lower production costs and improved international competitiveness (Porter and van der Linde 1995a, b). Repetto et al. (1997) in looking at climate policy specifically, argue that GHG commitments will not harm U.S. competitiveness and could actually stimulate sector investments. Berman and Bui (2001) look at a related issue – air quality, from the perspective of a key sector, evaluating the impacts of specific air quality regulations on refineries in California. They found that oil refineries meeting more stringent environmental standards in the Los Angeles Air basin increased productivity and efficiency because of the redesigned production processes required for compliance.

The positive implications of environmental regulations on competitiveness, however, are not consistent in the literature (Jaffe et al., 1995). Jaffe reviewed empirical studies assessing impacts of environmental regulation on competitiveness and while he found "…relatively little evidence to support the hypothesis that environmental regulations have had a large adverse effect on competitiveness…" he also did not find that they had improved international competitiveness either. Jeppesen et al. (2002) agreed with Jaffe and concluded that the empirical evidence was generally inconclusive with respect to the impact of environmental regulations on competitiveness.

The most recent effort to address this debate looked again at the implications of climate policy in California.[1] Arnold Schwarzenegger, California's Governor, has committed to taking significant action on climate change and a Berkeley group evaluated eight of the potential policies being considered (Hanemann et al., 2006). Using the Berkeley Energy and Resources (BEAR) model, they found in aggregate, these eight policies had benefits that exceeded the costs. The authors found that many GHG policies reduce energy use, which in turn lowers spending on energy and allows saving to be spent on goods that increase economic growth and employment. "Climate action in California," they concluded "can yield net gains for the state economy, increasing growth and creating jobs." The authors go on to suggest that near-term effort will give California a competitive advantage with respect to technology and industries that will be needed to address climate change.

Notably, empirical evidence that environmental regulations have negatively impacted U.S. competitiveness is lacking. However, most of the above research (with the exception of Hanneman) was directed at past regulation and linked to the overall observed cost of a specific policy. Had policy costs been as high as some initial predictions, these impacts may have been much more significant. Fortunately, many of the initial projections of policy cost overestimated actual costs because economic models which forecasted these costs were not able to capture the full resilience and innovation potential of our economy. Many economists and environmentalists have long argued that economic models over estimate the costs of environmental policy because they do not accurately account for this innovative potential, and this over estimation of costs seems likely for climate policy as well.[2]

13.1.2 Economic Models of Climate Policy

Hundreds of analyses, using a variety of economic models and assumptions about how the economy will behave, how technology will develop, etc. have been published on the macroeconomic implications of climate policy in the last decade.[3] One of the standard tools for analyzing macroeconomic impacts of any policy is a specific type of "top down" model called a computable general equilibrium (CGE) model.[4] CGE models are composed of systems of mathematical equations and large amounts of data that refer to separate but connected elements relevant to the entire economy, like production and consumption; inputs of capital, labor, and energy; investment, taxes, etc. Particularly useful for approximating and comparing the economies potential long-term response to policies, state-of-the-art CGE models solve these equations simultaneously to identify the relationship between elements and to the broader economy.

Many of the initial cost estimates of climate policy looked at economy-wide implications associated with implementation of the Kyoto Protocol. The Protocol requires developed countries to reduce emissions on average 5% and the U.S. to reduce its emissions on average 7% below 1990 emission levels during the 2008–2012 time frame.[5] A wide range of cost projections associated with meeting the Kyoto target were produced by CGE models in the late 1990s. Table 13.1 summarizes the most commonly cited results from MIT, Charles Rivers and Associates (CRA), the U.S. Energy Information Administration (EIA), the Council of Economic Advisors (CEA), Wharton Econometric Forecasting Associates (WEFA) and the Tellus Institute.

In 2010, the studies projected that the price of one metric ton of carbon would range from \$23/ton to \$393/ton. The projected range of impacts on GDP was similarly diverse. In 2010, GDP impacts relative to our projected GDP without Kyoto ranged from +0.15 percent at the low end, suggesting economic gains from the policy to −4.2 percent at the high end of costs. Citing the high cost estimates, critics of the Kyoto Protocol used words like "devastating consequences" and "grave damage" to refer to impacts on the U.S. economy from implementation of this international agreement.[6] Hence, one more source of the myth that climate change policy will bankrupt our economy.

More recently, three of the of the above economic models, MIT, EIA and CRA have been used to assess the economic consequences of the more moderate domestic climate policy proposed by Senators' McCain and Lieberman – known as the Climate Stewardship Act (SA2028) of 2004 and a revised version known as the Stewardship and Innovation Act (S1151) of 2005. Their proposed policy is a comprehensive framework of elements that includes a mandatory cap on industrial emissions but allows firms the flexibility to "trade" emission reductions under the "cap" to ensure cost-effective overall compliance. The cap required by these

Table 13.1. Comparison of Results for – Kyoto Models of 7 Percent Below 1990 Levels

Projection[a]	MIT[1]	CRA[2]	EIA[3]	CEA[4]	WEFA[5]	TELLUS[6]
		2010				
Carbon price (2001 Dollars per metric ton)	198	123	393	23c	299	NA
Percent change in actual gross domestic product from reference projection	−1.5[b]	−1.3	−4.2	.1%	−3.2	+.15
Actual GDP impact billion 2001 dollars	−177	−146	−501	−12	−375	+16
		2020				
Carbon price (2001 dollars per metric ton)	134	198	344	NA	406	NA
Percent change in actual gross domestic product from reference	−1.5[b]	−1.7	−.76	NA	−2.0	NA
Actual GDP impact Billion 2001 dollars	−206	−248	−105	-NA	−290	NA

Notes:

[a] All numbers converted to 2001 dollars using the CPI.

[b] MIT provided a range from −0.5 to −1.5 percent for change in GDP, to be interpreted as minimum and maximum losses to the economy. Because GDP was not provided for the MIT reference case, EIA noted the reader should assume a central value for GDP of 11,866 billion in 2010 and $13,759 in 2020 (2001 dollars). Consequently, the range of losses is $59 billion to $177 billion in 2010 and $69 billion to $206 billion in 2020.

[c] CEA provided a range of carbon prices from $15–25 dollars per ton, and a cost of $8–13 billion per year converted to 2001 dollars for years 2008–2012.

[1] MIT uses the Computatable General Equilibrium (CGE)) model called EPPA model. EPPA is recursive dynamic and as such future policies and events have no impact on near term decisions or outcomes.

[2] CRA uses the CGE MultiRegionalTrade (MRN and MS-MRT) models.

[3] EIA uses the CGE National Energy Modeling System (NEMS) model.

[4] From Testimony by Dr. Janet Yellen to U.S. Senate Committee on Energy and Natural Resources 25 March 1999, based on stated modeling results from the Second Generation Model.

[5] WEFA- Wharton Econometric Forecasting Associates has now merged with DRI to form the consulting firm Global Insights.

[6] TELLUS used a modified NEMS model.

Source: EIA (1998) Cost Estimates of the Kyoto Protocol http://www.eia.doe.gov/oiaf/kyoto/tbl30.html and http://www.eia.doe.gov/oiaf/kyoto/tbl31.html and http://www.eia.doe.gov/oiaf/kyoto/pdf/sroiaf9803.pdf. CEA cost estimates from www.gcrio.org/onLnDoc/senate_energy990325.html, WEFA cost estimates from WEFA (2002) and TELLUS estimates from Bernow (1999)

proposals is stabilization of year 2000 emission levels by 2010. Figure 13.1 illustrates the level of reduction required by the Kyoto Protocol in comparison to the level required by the McCain-Lieberman proposals. As can be seen from the figure, the target level of emissions proposed by McCain and Lieberman is significantly less stringent, and with a longer time for adjustment, than that proposed under the Kyoto Protocol. Table 13.2 compares economic results for this more moderate policy.

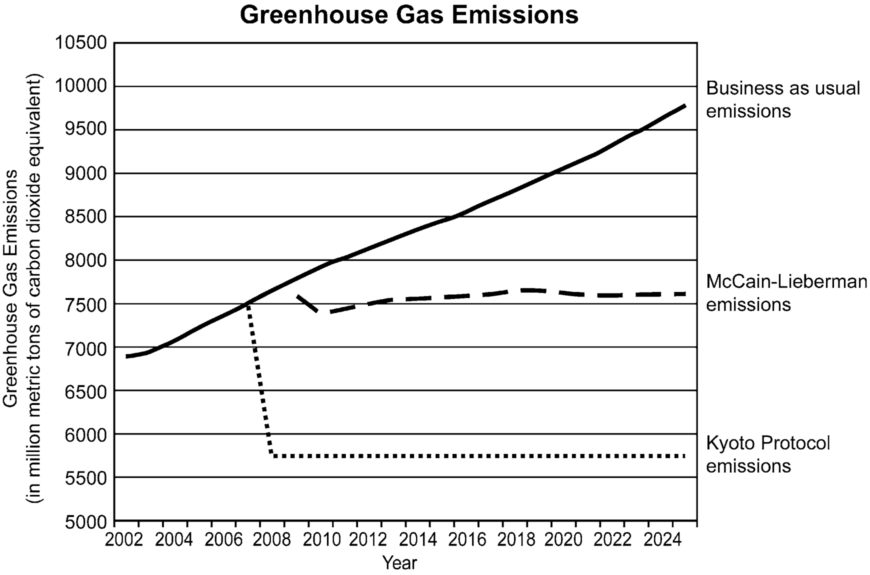


Figure 13.1. Emission levels Kyoto Protocol vs. Climate Stewardship Act (Business as Usual and McCain-Lieberman Emissions – EIA (2004, Table 118). Kyoto Protocol Emissions – EIA, 1998)

Table 13.2. Comparison of results for SA2028 reducing carbon emissions to 2000 levels

Projection[a]	MIT[b]	CRA	EIA	TELLUS[c]
	2010			
Carbon price (2001 dollars per metric ton of carbon)	32	27–69	55	29
Percent change in actual gross domestic product from reference projection	−.02	−(.2–.4)	−.26	NA
Billion 2001 Dollars	−1.7	−227	−32	−5
	2020			
Carbon price (2001 dollars per metric ton of carbon)	53	44–110	125	81
Percent change in actual gross domestic product from reference projection	−.02	−(.4–8)	−.22	NA
Billion 2001 dollars	−2.4	−311	−36	+30

[a] All dollars converted to 2001 dollars using the CPI

[b] MIT scenario 12

[c] Tellus prepared this analysis for Natural Resources Defense Council (NRDC) and utilized a modified NEMS model

Sources: MIT estimates from Paltsev et al., 2003; CRA estimates from Smith et al., 2003; EIA estimates from EIA, 2004; and TELLUS estimates from Bailie et al., 2003.

Again, because of the assumptions and the inherent differences in the model used, the ranges of impacts suggested by the economic models vary widely, as they did for the Kyoto Protocol impacts. Carbon price estimates in 2010 ranged from the low Tellus estimate of $29/ton to the high CRA estimate of $69/ton. The range was even wider in terms of the expected impact on economic activity. CRA projected that the economy would lose $311 billion per year by 2020; in contrast, Tellus projected that the economy would see a net benefit of $30 billion.

Economic models only estimate how the economy will perform given very specific assumptions and only as allowed by the structure of the model. As can be seen from the previous examples, different assumptions and different structures yield very different results.

Again, because of the assumptions and the inherent differences in the model used, the ranges of impacts suggested by the economic models vary widely, as they did for the Kyoto Protocol.

13.1.3 Model Assumptions

In general, estimates of the costs of reducing greenhouse gas emissions in the various models depends critically on the assumptions about how the economy works and how the following elements are represented: (1) the degree of foresight that decision-makers have in the marketplace; (2) the degree of flexibility in the economy (how easily it can adapt to change); (3) how technological change is characterized; (4) the sensitivity of energy demand to price changes; (5) the specific policies included; (6) how economy and environment will perform in the absence of climate policy (the baseline or reference case); and (7) whether the benefits of avoided climate damage are included. With respect to how the above elements impact the modeling results of climate policies John Weyant (2000) found generally that:

- the more optimistic models are about the degree of flexibility in the economy (ease of substitution between old and new technologies), the lower the economic impact;
- the more responsive emission reductions are to energy price increases, the lower the costs;
- including the impacts of induced technological change will have modest impacts in the short run but more significant impacts in the longer term;
- how revenues raised through carbon taxes are reused will affect program costs;
- the lower the assumed baseline or reference case forecast of emissions, the lower the cost of achieving any specific target (but this may also decrease reduction options);
- the more the model accounts for the benefits of emissions reductions, the lower the net economic impact; and finally
- assumptions about the specific policies included – in particular, the inclusion of multiple gases and global trading will produce lower cost estimates.

Tellus (Bernow, 1999; Bailie et al., 2003) had by far the most optimistic model results for the above elements in comparison to those models previously discussed. Without even factoring in the benefits of avoided climate change, Tellus (Bailie et al., 2003) concludes that in 2020 there is a net benefit associated with a multi-pronged approach like that suggested by the McCain-Lieberman climate change policy proposal.[7] In stark contrast, WEFA appears the least optimistic. Specifically, the WEFA study assumed a higher level of economic growth in its baseline, higher resulting emissions, and no complementary programs to reduce emissions and specifically no use of carbon sinks, international trading or offsetting emissions.[8]

With the advantage of hindsight, we now know that many of the Tellus assumptions were more accurate. Notably, international trading of greenhouse gases has already started. The European Union has just completed its second full year of its emissions trading program, which included all 25 member countries and includes reductions from the lesser, reductions from the lesser-developed countries through the Clean Development Mechanism (CDM).[9] We also know that the use of carbon sinks is allowed as part of Kyoto and that even here in the U.S. sinks are recognized as legitimate offsets by a number of state climate programs.

The sheer number of state climate related programs that are in development today also supports the assumption made by the Tellus model developers that complementary programs would be implemented (see Box 13.2). EIA and CRA, while they assumed trading was allowed, assume that no other climate related policies (at the state or federal level) would be enacted (even though several states including nine northeastern states had already announced their intention to develop a regional cap and trade program). EIA and CRA also structured their model to focus only on CO_2 emissions and thus were not able to capture significant low cost opportunities to reduce non-CO_2 greenhouse gases (GHGs) in their models.[10] MIT, in contrast, allowed trading and non-CO_2 gases to be reduced. As such, MIT found considerably less fuel switching in our energy supply was required to meet the target, and their result was a lower cost estimate.

Box 13.2. State Actions on Climate Change

Almost Every State is Doing Something on Climate Change or Clean Energy

State Statistics – June 2006:

- 8 states have initiated the Regional Greenhouse Gas Initiative (RGGI), the first mandatory GHG cap and trade system in the U.S (see figure)
- 10 states are poised to follow California's GHG emissions standards for vehicles (CT, MA, ME, NJ, NY, OR, PA, RI, VT, WA)

(Continued)

Box 13.2. *(Continued)*

- 22 states plus D.C. have renewable portfolio standards (RPSs)
- 28 states have climate action plans
- 14 states have statewide GHG targets (CA, CT, DE, MA, ME, NH, NJ, NM, NY, OR, RI, VT, and WA)
- 3 states require utilities to offset some portion of their emissions
- 40 states have at least one utility that permits customers to sell electricity back to the grid through "net metering"
- 35 states have utility "green pricing" options
- 27 states have incentives that promote ethanol, and 3 of those states have mandates;
- 22 states have public benefit funds that support energy efficiency; the funds in 14 of these states also support renewable energy.

Regional Greenhouse Gas Initiative 2006

- Cap applied initially to electricity generators producing more than 25 MW
- Phase I goal is stabilization at 150 million tons 2009–2015
- Phase II 10% reduction between 2015–2020

- Offsets allowed: 1st group includes landfill methane, SF-6 from transformers, end use combustion efficiency, manure management, afforestation (geographic scope increased if price becomes greater than \$7/ton CO_2)
- Proposed linkage with EU and CDM flexible mechanisms (if allowance price becomes greater than \$10/ton CO_2)

For more information see the RGGI website at http://www.rggi.org/

The importance of the scenario (and policy) modeled cannot be overstated. As Weyant found, models (and policies) that include international trading will result in lower costs. More recent efforts by (Reilly and Prinn, 2006) and others at Stanford's Energy Modeling Forum have also found that including non-CO_2 gases in the models (and in policy) reduces program costs. By not including these other gases, EIA and CRA results thus likely overstate the costs of taking action. Clearly, the importance of including these other gases has not been lost on state climate policy efforts. For example, the Regional Greenhouse Gas Initiative (RGGI) just launched in eight New England states intends to allow reductions of non-CO_2 gases as offsets and their modeling projects that an ample supply is available in the \$2–4 per ton price range.

The myth that climate policy will bankrupt the economy is based in large part on high costs estimates from a few models (often derived from unrealistic assumptions) and on the perception that these additional costs will impact our competitiveness. It is important to understand the types of models, the key assumptions these models rely on, and whether the model developers have an agenda, so as to gauge the relative predictive power of the models. Undeniably, economic models will never provide perfect predictions of the future. Instead, when they use realistic assumptions and clearly identify those employed, they are useful for evaluating the relative merits of alternative policy design elements. Their utility comes from their ability to integrate economic and sometimes scientific theories and large quantities of data into a consistent framework for evaluation of options. Economic models can best be used to provide insights, not absolute answers and these insights must be judged based on the validity of the information going into the model.

While many models of climate policy exist, the models discussed in this section are those most often referenced in the debate about climate policy and it is important to note that not all of these predict dire consequences. MIT's EPPA model (one of the world's premier energy/economic models) of the economic implications of the McCain-Lieberman Bill, for example, suggests that GDP will only be reduced by .02%. Differently phrased, in 2020 the U.S. economy is projected to grow from its 2006 level by 52.34% instead of 52.36%.[11] Such a modest impact does not even hint at bankrupting the economy and as other studies have shown, elements like labor costs have much more of an influence on competitiveness than environmental regulation.

13.2. BENEFITS – THE OTHER KEY ELEMENT

Another issue associated with economic models and the myth that policy is too costly is that most models do not fully incorporate the benefits of avoiding climate induced damages. Instead, while a few models have tried, most focus simply on the cost of policy. As previously mentioned, the larger the extent that models account for the benefits of emissions reductions, the lower the net economic impact. Unfortunately, even models that have tried to include benefits have not been fully successful, in part because not all outcomes and impacts are quantifiable. Jorgenson and Goettles (2004) found that in general, knowledge of the direct and indirect impacts associated with a changing climate was "incomplete" and as such model estimates are likely to underestimate the benefits of climate policy. For this reason, the following section discusses the potential consequences but does not provide a comparison of estimates. Our purpose is to provide context and justification for climate policy and to specifically point out that without a consideration of the benefits of action, *any* policy will likely seem too expensive.

13.2.1 Potential Impacts of Climate Change

An ever increasing, scientific consensus has been reached that global warming is largely the result of emissions of carbon dioxide and other greenhouse gases from human (anthropogenic) activities including industrial processes, fossil fuel combustion, and changes in land use, such as deforestation. Researchers with the Intergovernmental Panel on Climate Change (IPCC, 2001a) have found that unless these emissions are slowed and eventually eliminated, additional warming of 2–10 °F is projected by the end of the 21st century.[12] Warming in the next century is projected to be even higher – perhaps two to ten times greater than the last. With these types of changes, a fundamental and potentially irreversible disruption of global ecology and natural systems is expected, both in this country and around the world. These expected disruptions impose a cost on our society and avoiding these impacts consequently can be thought of as the benefits of taking action on climate change.

While the U.S. economy as a whole appears to be resilient to a *gradual* change in climate that comes from a moderate increase in temperature (up to 4–7 °F), the economic impact on individual sectors or regions in the United States could be far more pronounced. Smith (2004) found that the Southeast and the Southern Great Plains are at most risk due to their low-lying coasts and the impacts of warmer conditions on agriculture. Sectors with long-lived infrastructure, such as water resources and coastal communities, will have the most difficulty adjusting. Smith concluded that the financial costs of adaptation (in terms of only infrastructure costs) to a 0.5m sea level rise by 2100, ranged from $20–138 billion depending on whether only the most valuable coastal property is protected or all developed coastal areas are protected. Because states typically do not have the financial resources to manage these huge costs, they will likely have to be borne at the federal level; further extending the damage to the entire economy.

To assess the economy-wide impacts of climate change, Jorgenson and Goettle again utilized economic modeling based on a range of climate change scenarios and related impacts. Although these results are not meant to be conclusive, they do suggest a range of potential benefits (avoided costs) that might be expected. Specifically, with gradual warming the United States may experience a 0.7–1.0% gain (under optimistic assumptions), or a 0.6–3.0% loss (under pessimistic assumptions) in GDP by year 2100. As climate change continues, however, these authors found that beyond critical thresholds, any benefits diminish and, ultimately reverse as the U.S. economy attempts to adapt. While some sectors may enjoy gains at low levels of warming (for example improvements in agriculture), beyond critical temperature thresholds, these benefits diminish and eventually become costs.

The results from Jorgenson and Goettle represent, at best, only a partial assessment of the full range of potential benefits. Certain market sectors (e.g., tourism) and a variety of indirect effects (e.g., climate change induced healthcare expenditures) were not included by Jorgenson and Goettle because of a lack of data. In addition, the economic modeling of the benefits does not account for critical non-market impacts such as changes in species distributions or losses in biodiversity and ecosystem services. Admittedly, attaching an economic value to all potential impacts is extremely difficult but the knowledge that these impacts exist would almost certainly offset any temporary benefits and add to the negative impacts that could be expected.

Significantly, most reports that have looked at the economic impacts associated with a changing climate, including Jorgenson and Goettle, have only looked at the implications of gradual and linear warming scenarios. Recent scientific evidence regarding global ice cover and hurricanes suggests that the climate is, in fact, warming faster than originally projected.

Glaciologists and oceanographers have been surprised by the unprecedented rates of change in global ice cover, both for Arctic sea ice and land based glaciers and ice sheets. In Greenland, for example, 15 years ago glaciologists believed its ice sheet was in balance (i.e., not losing or gaining ice). Today glaciologists are documenting rapid melting. The Greenland ice-sheet is the second largest land based ice sheet, with enough water to raise the global sea level by 6 m if melted (Rignot and Kanagaratnam, 2006). Similarly Western Antarctica is losing ice rapidly. Until recently, East Antarctica was thought to be gaining ice, but now is thought to be just in balance, such that future warming could quickly shift it to net ice loss. Overall, Antarctica appears to have lost about 450 km^3 of ice, roughly the volume of Lake Erie, in the past three years (Velicogna et al., 2006). For perspective on the significance of this occurrence, Antarctica holds enough ice to raise the sea level by 70 m if melted.

The evidence that hurricanes are becoming more intense is also increasing. In 2005, two independent studies found that hurricanes were becoming more intense worldwide (Emanuel, 2005; Webster et al., 2005). All oceans where tropical cyclones develop showed this change in recent decades. Skeptics point toward natural climate variability but overlook the well established knowledge that natural cycles do not occur in-sync across the various basins. Instead they tend to vary in opposite phases between basins like the Atlantic and Pacific. This recent warming trend, however, has intensified in all six of the tropical cyclone producing ocean basins and represents more evidence that human activities are affecting the climate, consistent with the enhanced greenhouse effect and not with natural variability alone.

Accelerated losses of ice from the poles, sea level rise and increased hurricane intensity have raised important questions about the risks facing coastal development and populations (almost 53% of the U.S. population lives along the coast (Crossett et al., 2004). One recent study by researchers at Columbia University (2005) looked at this increased risk for the greater New York City region. They estimated that the annual expected impact associated with climate change on regional infrastructure could be around $100–200 million per year. While this report estimated that such a loss can be absorbed by the region's $1 trillion economy, it also notes that losses do not occur with any type of annual frequency. Instead the report suggested they tend to occur as extreme events, which could significantly impact the region's low-lying transportation infrastructure, including tunnels, bridges, airports and roads – all of which are particularly vulnerable to flooding. Such damage could cost the region tens and potentially hundreds of billions of dollars according to the report.

Prior to the summer of 2005 this type of damage, while alarming, seemed fairly unlikely to most people. Who could imagine a major U.S. city flooded to the point that it had to shut down for an extended period of time? Images of Hurricane Katrina hitting New Orleans and the coastline of both Mississippi and Alabama have changed the perception of what is possible. In terms of the cost of that storm, David Holz-Eakin, Director of the Congressional Budget Office (CBO, 2006) has estimated that the loss associated with physical capital alone would likely be in the range of $70–130 billion. This estimate does not include the loss of life, the long-term impacts on the state and national economy, or non-market value of the damage on the ecosystems that were devastated. Putting this estimate into perspective, the cost for this one storm is at the upper end of the range of cost associated with sea level rise suggested by Smith (2004) for the entire United States.

Although we cannot be certain global warming intensified Katrina per se, it clearly has created circumstances under which powerful storms are more likely to occur. A reasonable assessment of the science suggests that we will face similar events again. Climate models predict that powerful storms are likely to happen more often than we have been accustomed to in the past and may become more powerful over time. As sea level rises, infrastructure losses from coastal storms and floods are much more likely to increase.

Weather related damages and costs have always been a fact of life but we are now looking at dramatically increasing those costs. Munich Re, an insurer of weather related damage has looked at storm related impacts and the following two graphs (see Figures 13.2 and 13.3) illustrate the trend that they have observed. Notably their data reflect an increasing number of weather related events and a growing cost of weather related damages.

As suggested by the Columbia report, recent events in Louisiana and Mississippi, and the trends that Munich Re has identified, storm related impacts will impose lasting costs on the U.S. economy and on the global economy as well.

While substantial uncertainty still exists about the exact nature, the extent of impacts, and the speed of occurrence, this should not be interpreted as certainty of no adverse impacts. The significance of these impacts and their associated costs will depend on the speed of change and our adaptive ability. It is important to realize there are real costs associated with a changing climate and with not taking action. Although some interest groups continue to claim that climate policy is too expensive and will wreak devastating consequences on the U.S. economy, it appears that the opposite may be true. Failure to act could result in regional impacts that have profound implications (some of which can be monetized and some of which cannot not) for individual states, the country and the globe as a whole. Putting climate change impacts into this context, Margaret Beckett, U.K.'s Secretary of State for Environment, Food and Rural Affairs has said "By comparison to the potential cost of damage due to climate change, the cost of long-term global action to tackle climate change is likely to be short-term and relatively modest" (Schelnhuber et al., 2006 Foreword). Nevertheless the myth persists here in the U.S. that climate change policy is too expensive. From the preceding pages, it should be obvious that *not* taking action is likely the more expensive option.

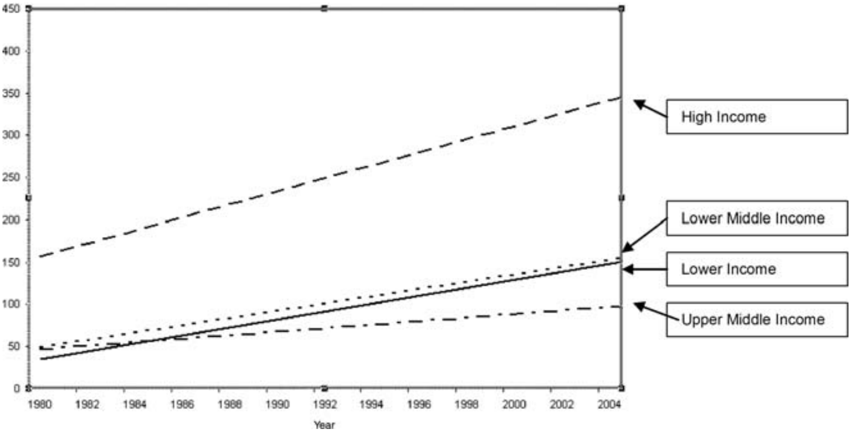


Figure 13.2. Number of weather catastrophes (1980–2004) in economies at different stages of development* (Adapted from Munich Re data, 2005 Geo Risks Research)
*Classification as per World Bank, 2004. High Income, GDP per capita > 9385 U.S.$; Upper Middle Income, GDP > 3036-9385 U.S.$; lower Middle Income, GDP > 765-3035 U.S.$; Lower Income, GDP < 765 US$

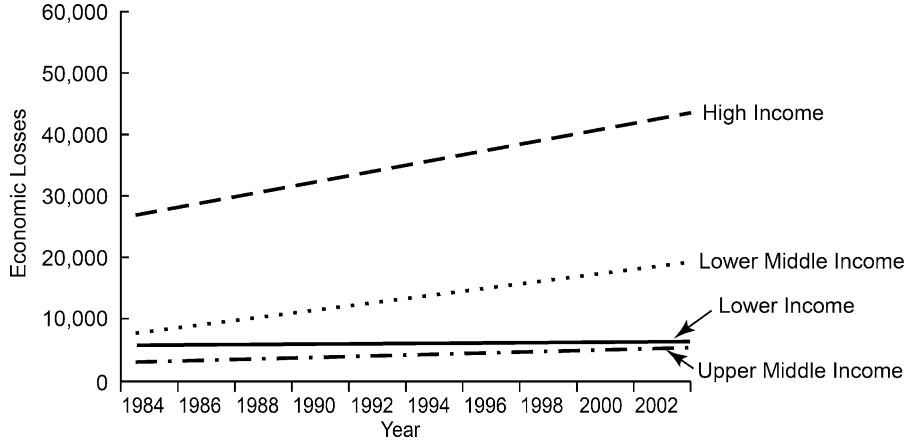


Figure 13.3. Economic damages from weather events (in millions of 2004 dollars) in economies at different stages of development* (Adapted from Munich Re data, 2005 Geo Risks Research)
* Classification as per World Bank (2004). High Income, GDP per capita > \$9385; Upper Middle Income, GDP > \$3036–9385; Lower Middle Income, GDP > \$765–3035; Lower Income, GDP < \$765

13.2.2 Timing

The longer we wait to take meaningful action, the worse the problem gets and the less flexibility we have to avoid or minimize the impacts and costs associated with climate change. The problem is getting worse because greenhouse gas emissions are accelerating, concentration levels are rising and the earth is heating up. Figure 13.4 illustrates the rapid increase in global emissions and concentration of carbon dioxide, the principal greenhouse gas.

Delaying action has several consequences that can directly increase the costs of climate change. First, higher atmospheric concentrations of CO_2 and higher temperatures (even slightly higher sustained temperatures) can cause more near term impacts like coral bleaching, species extinction, and even heat related deaths.[13] Next, the more rapid these increase, the less time we have to adapt and prepare for change. Gradual changes in temperature presumably yield gradual shifts in ecosystems, gradual sea level rise, etc. and give us more flexibility and time to prepare, adapt and cost-effectively manage the effort needed to address this issue. In other words, more rapid responses are often more costly. Furthermore, as emissions and concentration increases, the risk of abrupt and catastrophic changes to the climate increases.

In most simulations of climate change impacts, CO_2 concentrations rise slowly over time and the climate system is assumed to respond like a dial that is slowly turned up over time. As noted earlier, many scientists, including those with IPCC, NASA, Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the National Research Council (NRC), now suggest that

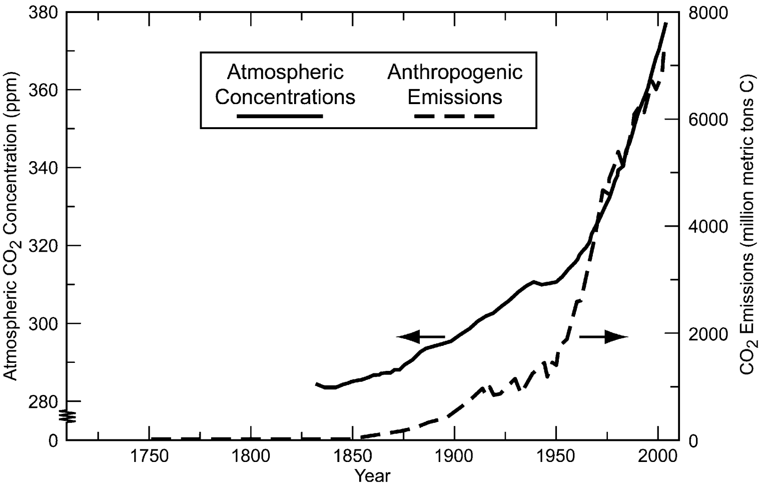


Figure 13.4. Trends in atmospheric concentrations and anthropogenic emissions of Carbon Dioxide (Oak Ridge National Laboratory, 2004)

impacts may not be gradual. Instead, they warn that there could exist "dangerous" threshold concentrations in the atmosphere when if met, could trigger large scale, potentially abrupt changes to the climate system (IPCC, 2001b; Hansen et al., 2005; Preston and Jones, 2006; NRC, 2002). So instead of a dial we have a switch-like affect; as specific threshold levels are met catastrophic consequences are triggered. One example of such a change is the potential weakening or collapse of the North Atlantic Ocean's thermohaline circulation (the ocean circulation that produces the Gulf Stream) that could result if sea-surface temperature and fresh water from melting ice dramatically increases. A change like this one would radically alter the climate in the North Atlantic, likely making it significantly colder. Scientists believe that once such catastrophic events are started, they may be extremely difficult or impossible to reverse.

Identifying the link between concentrations, temperatures, timing and catastrophic events has been the subject of much research but while scientific knowledge has increased, specific thresholds have not yet been conclusively determined. Nevertheless because a consensus exists that dangerous threshold impacts are possible, concentration goals, like 550 ppm, 440 ppm and even recently 350 ppm have been suggested by IPCC scientists and others to help ensure that temperature increases are less than 2 °C relative to preindustrial levels (1861–1890).[14] The 2 °C goal is often cited as an objective because, as Meinshausen (2006) explains, above this temperature "cannot be assumed to be free of (potentially large scale) adverse impacts" (p. 265). As an example of such a large scale impact he mentions that Greenland's ice sheet could melt if regional temperature increases exceed 2.7 °C, and with this melt, sea level is expected to rise seven meters.

Avoiding this type of impact is consistent with the goal of the 1992 U.N. Framework Convention on Climate Change (UNFCC) which called for "stabilization of greenhouse gas concentrations in the atmospheric at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCC, 1992). Although the term "dangerous" requires a subjective assessment of how much interference is too much, avoiding catastrophic climate related events is likely a goal that everyone would agree to and furthermore would concur is worth the modest cost of climate policy.

The European Union has decided that because of the danger that climate change impact poses, the cost of policy is justified. They have formally adopted 2 °C (above 1990 levels) as their climate target and regard this as the highest temperature increase that can be sustained without unacceptable consequences for society and the environment. A European Environment Agency (EEA) report states that in order to achieve this goal by 2100, global greenhouse emissions need to be reduced substantially below present levels in coming decades (EEA, 2004). While there is no guarantee that meeting this 2 °C will prevent climate change, the goal is to minimize climate damage and avoid catastrophic events (see Box 13.3 for more details on EU efforts to address climate change).

The benefits of early action were also recently highlighted by Australian scientists who noted that while it is not possible to entirely avoid climate change impacts in Australia (because of the already committed build up of atmospheric concentration and additional heat in the earth's system), near-term emission reduction efforts can help prevent some of the worst-case impacts projected for that country (Preston and Jones, 2006). Specifically they assert that taking early action can help to avoid major precipitation changes, public health impacts, sea-level rise, coastal inundation and erosion, and damage to coastal infrastructure. And perhaps most importantly, early action significantly reduces the risk of large-scale abrupt climate change.

The timing of efforts to address climate change does matter – to the scale of impacts and to costs associated with those impacts. According to IPCC, the greater the reductions in emissions and the earlier they are introduced, the smaller and slower the projected warming and rise in sea levels (IPCC, 2001b). In other words, scientists from around the globe agree that immediate action to reduce GHGs offers us the best chance of minimizing climate impacts and avoiding catastrophic changes in the world's climate. The longer American policymakers put off or avoid taking meaningful action to reduce emissions, the more difficult it will be to reduce atmospheric concentration levels and the more risk we face of potentially disastrous and irreversible impacts. Putting off meaningful action increases the cost – both in terms of the absolute concentration levels that need to be reduced and in terms of costs that will be incurred as we cope with the consequences of a changing climate (e.g., rising sea levels, Gulf Stream changes, more intense storms, drier or wetter climates, etc).

Ignoring the costs of inaction, even as emissions and atmospheric concentrations rise, and focusing only on the cost of reducing emissions, skews the picture and the conclusions that can be drawn about the ultimate cost of any climate policy. Admittedly, some policy approaches will be more expensive than others but without a consideration of the benefits of action *any* policy could seem too expensive. Instead of asking whether policy is too expensive, we should be asking, "how can we best minimize these impacts" and "design policy that is least cost?"

Box 13.3. Climate Change Efforts in the European Union

The European Union (EU) is one of the international leaders addressing climate change. According to the latest emissions monitoring data the European Union has delivered on its long-standing commitment to stabilize emissions of CO_2 at the level of 1990 in the year 2000 (EC, 2006). It has also committed through the Kyoto Protocol Agreement to further reductions in the original 15 countries (EU-15) CO_2 emissions at an average of 8% below 1990 levels during the first commitment period 2008–2012.

To reach these targets, in March 2000 the EU Commission launched the European Climate Change Programme (ECCP), consisting of a range of policies and measures like incentives for renewable energy, energy efficiency and including the much discussed EU emissions trading scheme (EU-ETS). The EU ETS covers approximately 46% of the EU CO_2 emissions.

The EU-ETS officially began in January 2005 and, with its 25 member countries covering over 11,500 installations, it is by far the largest emission trading program in existence. The program has two phases: a warm up Phase I, which started in January 1, 2005 and goes through 2007 and its Kyoto compliance Phase II, which begins in January 2008 and goes through 2012.

Initially in Phase I, the EU-ETS covers only CO_2 emissions from ferrous metals (iron and steel), minerals (cement, glass, or ceramic production), energy (electric power and direct emissions from oil refineries) and pulp and paper. Applicable installations were identified in the National Allocation Plans (NAPs) submitted by each Member state. For the Phase I, 2005–2007, 6.6 billion allowances were allocated to companies for free. At the end of December 2006, allowance prices were just under $7 Euros per ton (approximately $19 U.S. dollars), this amounts to approximately 99 billion Euros worth of assets.

Emissions data from 2005, the first year of the program, and the price drop that occurred following release of this data in late April 2006, suggest that the initial allocation may have been overly generous. Market observers, like Point Carbon (an electronic news source which follows the carbon market), and even the EU's own Phase II, NAP Guidance report (EC, 2005) have suggested that Phase II industry targets may need to be more stringent to enable meeting the Kyoto target. Nine of the ten Phase II NAPS submitted have been required to significantly reduce their cap and allocation. On November 29th the EU Commission cut almost 47 million metric tons annually off of these nine proposals. Second Phase NAPs due in June of 2006, will lay out the specifics, including who is covered and whether firms will have to buy more of their permits. As of the writing of this chapter, however, it is too soon to determine whether these targets will be met but either way, they have established the trading infrastructure, determined country specific and industry specific targets, defined the commodity, implemented a consistent set of rules and verification requirements such that carbon trading is now a reality. All of this can only be regarded as a step in the right direction for addressing climate change.

For additional information please see European Commission environment web site at http://ec.europa.eu/environment/.

13.3. POLICY DESIGN IS AN IMPORTANT DETERMINANT OF COST

How we design climate policy matters. It matters to whether we will be successful and it matters in terms of the cost. Only a serious long-term international commitment to this issue will enable us to fully minimize the impacts of a changing climate.[15] Only a broad framework that takes advantage of all of our near-term opportunities and sets us on a path to speed low carbon technology innovation, development and implementation will ensure that this cost is as low as possible.

We need policies that will start a technology revolution because we need to shift our economy and the energy which powers it, to one with low carbon emissions. Such a change will not be easy nor will it be free but we can strive to ensure that the costs are as low as possible by looking at policies that: (1) harness the force of the market to send a clear, long-term signal that there is value in reducing greenhouse gas emissions; (2) promote technological change by giving firms the flexibility to innovate and by financially supporting technology development; (3) focus on a broad framework, rather than on a narrow set of options; and finally (4) start sooner rather than later because time allows us to better manage the costs of climate change policy.

13.3.1 The Force of the Market

Harnessing the force of the market requires establishing an explicit cost (or price) for greenhouse gas emissions. Emissions trading (one form of which is cap-and-trade) has emerged in the last several decades as one of the primary policy tools for establishing this price. Many recent climate proposals in the U.S Congress have included a trading component among their core policy elements.[16] A conventional cap-and-trade program establishes an economy-wide or sectoral cap on emissions (in terms of tons per year or other compliance period) and allocates a specific amount of tradable allowances (the right to emit a ton of GHGs) to emission sources, according to some predefined company target. The total number of issued allowances is equal to the cap. Firms have the flexibility to reduce their own emissions or purchase allowances for compliance with their own emissions target.

The cost effectiveness of emissions trading has been the subject of numerous studies and in general it has been found that the broader the trading system, the lower the costs (see Edmonds et al., 1999 for empirical estimates on how the scope of trading reduces cost). A broader program helps ensure that the least expensive reductions are utilized first. This is true whether designing a trading system for only one country or a trading system between countries. A broader trading scope that includes non-CO_2 gases, voluntary offsets, and intertemporal flexibility with banking and borrowing has also been shown to lower the cost of meeting a predefined target.

13.3.2 Technological Change is Needed

A fundamental advantage offered by trading is the incentive for innovation that it provides and because addressing climate change will require that we go beyond current technology, policy that spurs innovation is critical. In comparison to traditional environmental regulation that specifies which technology must be used, emissions' trading is widely acknowledged as providing a financial incentive for firms to continuously seek innovative ways to reduce their emissions (improving their own processes and/or technology or paying other to improve theirs). Innovation notably helped ensure that the goals of the Acid Rain Program were met at a cost as low as possible (see Box 13.4) and this lesson has not been lost on supporters of effort on climate change who believe that widespread innovation is crucial for dealing with this issue.

Emissions' trading, however, is not the only policy needed. To spur this technology revolution cost effectively, we need policy that will both push and pull technology out of R&D, off the shelf and into reality and common usage. Goulder (2004) quantitatively explored the issue of technological innovation using state-of-the-art economic modeling and analysis. He found that to spur technological change and reduce greenhouse gas emissions most cost effectively, both policies that boost technological innovation, such as R&D funding, and policies that limit emissions, such as a GHG cap-and-trade program, are required. Results from his model suggest that the costs of meeting a long-term CO_2 emissions target using both R&D subsidies and a carbon tax (or cap-and-trade) is roughly 10 times less than with R&D subsidies alone.

Analysis conducted for the U.S. Climate Change Technology Program (CCTP)'s Strategic Plan corroborates the potential for technological breakthroughs to cut the cost of reducing greenhouse gases. In Chapter 3 of the draft CCTP Strategic Plan, various advanced technology scenarios are analyzed over the course of the 21st century for cases where global growth in GHG emissions were assumed to slow, then stop, and eventually reverse in order to ultimately stabilize GHG concentrations at levels ranging from 450 to 750 ppm. The cost of achieving different levels of emission reductions with advanced technologies was lower by as much as a factor of 3 when compared with scenarios that did not benefit from technological advances (CCTP, 2005). Technological breakthroughs and policy that will pull these breakthroughs into widespread commercial usage will be essential to ensure the cost-effective transformation of our economy to one with low carbon emissions.

Goulder also found that timing affected the cost of policy. His modeling suggested that announcing policies in advance lowers the costs of meeting emission reduction targets. For example, announcing a $25 per ton carbon tax 10 years in advance his results suggest can reduce discounted GDP costs by about a third compared to the same climate policy imposed with no prior notice. Announcing policies that will pull technology into use well in advance is important because it allows firms the flexibility to make changes when they are least costly. If firms have some certainty about the level of emission reductions that will be required now and in the future, they will make their long-term capital investment decisions with full information and will choose a path that minimizes their overall costs. Rather than mandating an immediate technological change (which would be quite costly), policies that take advantage of the natural investment cycle for industry provide a significant opportunity for low cost deployment of new, emission reducing technologies (Lempert, 2002).

Box 13.4. Success of the Market – Acid Rain

The U.S. Acid Rain Program established by Title IV of the 1990 Clean Air Act Amendments, is an often cited cap-and-trade success story. It has been hailed as a success because not only was the economy-wide SO_2 target reached; it was reached at a cost significantly below that projected by many of the economic models prior to its implementation. In addition, many view it as a success because it demonstrated the innovation incentive, fundamentally an advantage of trading over more conventional environmental regulation.

In this program emissions of SO_2 were significantly limited and firms had the ability to make their own reductions or buy allowances from others. The Acid Rain Program officially began in 1995 and was implemented in two phases: 1995–1999 and 2000 – present. The end result was a trading system with a national cap of nine million tons of SO_2 emissions per year applied to virtually all electricity generating units in the United States.

Early projections of expected average cost for the first phase of the program ranged from a high of $307 per ton of SO_2 removed to $180 per ton (in 1995 dollars). Ellerman (2000) estimated that the actual costs were closer to the low end of the projections in the $187–$210 range. Relative to the alternative command and control policy, Ellerman concludes that compliance costs were reduced as much as 50% (Ellerman, 2003).

The U.S. Acid Rain emissions trading program, has also been seen as a success because of the stimulus it provided for innovation. Describing the resulting innovation, Burtraw et al. (2005) points to fuel blending, scrubbers, and transportation as the main beneficiaries. Prior to Title IV, coal-fired power plant boilers were designed for specific types of coal and were thought to require expensive retrofits to allow the use of lower sulfur coal. Experiments with fuel blending done because of Title IV, demonstrated that upgrades were easier and cheaper than originally thought, thus expanding the demand for Western coal in the Eastern U.S. Scrubber improvements, including SO_2 removal efficiency, better performance and overall reduced operating costs were also motivated by the policy. Rail transport (for low-sulfur coal) also benefited from investment and innovation in rail line upgrades, locomotive and car designs, again, due in part to the Acid Rain program (Environmental Law Institute (ELI), 1997).

As the first economy wide cap and trade program, it provided many lessons for controlling greenhouse gas and served as a model for later environmental trading programs.

The timing of these investment decisions is particularly important to cost because the primary sources of greenhouse gases in our economy are the capital equipment used by electric generation plants, factories, and transportation infrastructure. These are long-lived and expensive. Replacing infrastructure and introducing new technologies gradually though will be less expensive than requirements for accelerated near-term investments in infrastructure or technology.

Unfortunately, today we see little effort to motivate the technological change that is needed. In particular, the energy sector continues on its traditional carbon path using conventional fossil fuel technology – without many signs of substantial change. One reason for this is that there are fundamental market and policy forces that have kept technology revolution in the energy sector from happening. Developing the technology to replace the existing and entrenched energy system will require massive investment – some suggest on the scale of the Manhattan Project from the 1940s. A recent review of the Climate Change Technology Program's R&D portfolio by Brown et al. (2006) emphasized the need for greater investment in exploratory research addressing novel and advanced concepts to uncover "breakthrough" technologies. Such research they suggest could lead to revolutionary advances in technology and thereby dramatically change the way energy is produced, transformed, and used in the global economy. The portfolio review also concluded that success will require the pursuit of multiple technology pathways; no single technology is sufficient to address the impacts of climate change.

Both industry and the federal government, however, have reduced investment in energy research and development. Data from DOE show that over the 25-year period 1978–2004, U.S. government investment in energy R&D fell nearly 60% (NCEP, 2004). The National Energy Policy Commission (NCEP) reported that private sector investment in energy R&D also fell from 0.8% of sales in 1990 to 0.3% of sales in 2004. For comparison, private sector R&D investment in the pharmaceuticals is about 12% of sales. The Commission concluded that the energy sector was the least R&D intensive high tech sector in the entire U.S. economy.

While policy is needed that will motivate investment in energy technology, policy is also needed to pull this technology into use. Technology developed but not used is, by any measure, too costly. However, many people who concede that government has a role in fostering energy R&D simply stop there. Once the technology is developed, they say, consumers will simply go out and buy it. In fact, experience does not bear this out. Lempert (2002) found that the *availability* of new technology rarely influences the rate at which firms retire older, more polluting plants and adopt new more efficient capital equipment. Without a policy that puts into place a demand for low carbon technology, adoption of these technologies is too slow, too inconsistent and too expensive to move the economy to where it needs to get by mid-century.

13.3.3 A Broad Policy Framework will Help Reduce the Cost

Pushing and pulling technology into the market will help us achieve large scale emission reductions cost effectively. Focusing on technology, however, is only part of the answer. Policy-makers here in the United States also need to promote a broad scope of innovation across all sectors of our economy including manufacturing, transportation, buildings, farming and our energy sector.

Policies that only target long-term technology innovation, however, may miss a low cost reduction option available today – efficiency improvements. Efficiency improvements save energy, reduce greenhouse gas emissions that come from energy production and use and from a cost perspective – often save money. “Low hanging fruit” is an illustrative name often applied to efficiency improvements.

The cost effectiveness of efficiency efforts is best demonstrated by the companies which have addressed climate change. British Petroleum for example, launched a program in 1998 to reduced GHG emissions from their operations 10% below their 1990 levels by 2010. They implemented a trading system within their own operations and they focused on reducing energy consumption and specifically improving energy efficiency. In 2001 they met their goal – 9 years ahead of schedule and they saved money. Lord Browne, BP’s CEO noted, “within the first three years we added $650M of value, for an investment of around $20M.”[17] Similarly successful, Dupont’s goal was 65% reduction of GHGs from 1990 levels by 2010.[18] Already they have achieved a 72 percent reduction and used seven percent less total energy in 2004 than in 1990, despite an almost 30 percent increase in production.

Economists are often skeptical that policy is without cost. After all, if energy efficiency improvements save money and firms are assumed to maximize their profits and minimize their costs, theory suggests, firms would be looking for such projects without any added incentive. A natural incentive exists to minimize input costs – especially for energy. But theory is not always correct – even BP and Dupont did not take advantage of low cost efficiency improvements until they specifically set out to do so. In reality, information barriers exist and there is a cost of overcoming those barriers. In addition, there can be political risks in taking action ahead of policy. If firms take action prior to policy, there is a risk that government won’t recognize early action and further efforts will be required. Also, not all firms have resource levels equivalent to BP or Dupont and many cannot risk even small investment for uncertain return. Again there is a role for government and specific policy on this issue – incentives, flexible GHG reduction targets, long-term goals and transition assistance can all help industry cost effectively reduce their GHGs.

Cost-effective climate policy will harness the power of the market, will stimulate technology development and deployment, will have an economy-wide scope and will provide the incentive for the low cost reductions that come from energy efficiency improvements. A combination of policies that allow flexibility, appropriate timing and provide assurance of a long-term policy commitment all go hand-in-hand with ensuring that climate policy is as cost-effective as possible.

13.4. CONCLUSION

A common theme echoed in arguments against climate policy and/or by those that advocate for delayed action on climate change is that the cost of acting now is too high. This myth is based primarily on the cost projections from economic models. Models and their estimates, however, are only as good as the data, the assumptions and the algorithms used. While models are useful for gaining insight into the relative merits of policy options, they are not intended to identify absolutes – be those costs or benefits, and can be easily skewed depending on the inputs. Many of the models that have looked at the costs of climate policy are limited in scope, make draconian assumptions about the flexibility and scope of the policy itself or the ability of the economy to respond resulting in findings that suggest *any* effort is too costly. Furthermore, models typically do a poor job of accounting for the long-term benefits of taking action (i.e., avoiding the damages of climate change). In fact because these benefits can be difficult to monetize, in many cases these benefits are not even included. Not accounting for these benefits lends support to the myth that we can't afford to take action on climate change. The point of this chapter is to put forward the idea that when taken as a whole, we can't afford to delay action. Postponing the enactment of a mandatory program makes the problem larger, increases the costs that future generations must bear and increases the risk of irreversible climate damage that could devastate regional economies.

To deal with this issue, a technology revolution is needed that will transform our economy into one with low greenhouse gas emissions. Four major forces must be brought to bear by our policy makers to ensure that this revolution begins soon and that costs are kept low. The power of the market must be engaged – the marketplace must see a value in lower greenhouse gas emission. A portfolio of new technologies must be developed and they must be pushed and pulled into widespread use. A broad framework of flexible policies aimed at all sectors of the economy must be enacted by government sooner rather than later. Government must signal the market that the time to start investing is now. It must send a clear long-term and consistent signal that it is committed to taking action.

Revolutionizing our economy to one with lower carbon emissions will not happen all at once, but the costs, while not trivial, need not be unmanageable. A combination of policies that start sooner rather than later, allow flexibility, appropriate timing and provide assurance of a long-term policy commitment all go hand-in-hand with ensuring that climate policy is as cost-effective as possible. While there is no one right answer on how best to start this revolution, there is a right time to start – now. Implementing climate policy now will not bankrupt the economy but waiting until the future might.

NOTES

[1] California, on its own, has a population equivalent to Canada's and GHG emissions levels similar to countries like France or Brazil.

[2] See for example, Goodstein and Hodges, 1997; Harrington et al., 2000; and Goulder and Laurence, 2004.

[3] See Weyant et al., 1996 for a more detailed discussion of the types of models that have been used to analyze this issue. See Bernow et al., 1998 for criticisms of CGE climate policy models.

[4] In contrast to "top-down" models, "bottom-up" models are typically based on engineering cost studies that represent the details of specific technologies. Often, they have very detailed data on the energy sector and much less detail about on other sectors and other broader macroeconomic elements of the economy.

[5] EIA estimated in its Annual Energy Outlook 2003 that U.S. emissions in 1990 were 6172 million metric tons of carbon dioxide equivalent; a 7% reduction implies a target level of emissions at 5740 million metric tons – Figure 1 (EIA, 2003). EIA, however, assumed this target was somewhat flexible because biological sinks could be included; as such a net reduction target of 3% was often discussed.

[6] See Antonelli et al., 1997 and Michaels, 2002 for critical opinions regarding the Kyoto Protocol.

[7] The Tellus results are similar to those of a study – ***Scenarios for a Clean Energy Future*** – conducted for the U.S. Department of Energy and the Environmental Protection Agency by researchers from five DOE national laboratories. An engineering-economic assessment of technologies and market-based policies, it looked at the benefits and costs of reducing carbon dioxide emissions in 2020 by 30–32% compared to a business-as-usual forecast. It concluded that the overall economic benefits of the technologies and policies could result in a benefit (avoided energy cost) equal to or greater than the cost of implementing the policies and investing in the technologies (Brown et al., 2001).

[8] A greenhouse gas offset is an emission reduction or atmospheric carbon removal made voluntarily by one entity and is assumed transferable for use by another.

[9] The Clean Development Mechanism (CDM) is one of the three market mechanisms established by the Kyoto Protocol. The CDM is designed to promote sustainable development in developing countries and assist Annex I Parties in meeting their greenhouse gas emmissions reduction commitments. It enables industrialized countries to invest in emission reduction projects in developing countries and receive tradeable credits for reductions achieved.

[10] Non-CO_2 gases refer to other greenhouse gases – including methane, nitrous oxide, and a number of manmade, industrial-process gases such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

[11] Estimated from EIA GDP projections available at http://www.eia.doe.gov/oiaf/aeo/excel/aeotab_19.xls

[12] IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988. Its role is to assess the scientific, technical and socio-economic information relevant for the understanding of human impact on climate change.

[13] A recent report authored by scientists with the National Science Foundation, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey warns of the increasing danger to coral and other marine life, as oceans around the globe become more acidic because of escalating carbon dioxide atmospheric concentration levels (Kleypas et al., 2006).

[14] For a more detailed discussion of the science surrounding dangerous climate change impacts see Schellnhuber et al., 2006.

[15] Because much of the world is already started to engage in this commitment by way of the Kyoto Protocol, our focus here is exclusively on U.S. policy.

[16] Emissions trading is a core element in the legislation proposed by Senators McCain (R-AZ) and Lieberman (D-CT) (Climate Stewardship and Innovation Act, S.1151), Senator Bingaman (D-NM) (Climate and Economy Insurance Act (S.A.868), Senator Feinstein (D-CA) (Strong Economy and Climate Protection Act, discussion draft), Representatives Gilchrest (R-MD) and Olver (D-MA) (Climate Stewardship Act, H.R.759) and Representatives Udall (D-NM) and Petri (R-WI) (H.R.5049). (The bill numbers shown here are from the 109th Congress.)

[17] BP CEO Lord Browne's Speech to the Institutional Investors Group. November 26 2003. Available at http://www.pewclimate.org/companies_leading_the_way_belc/company_profiles/bp_amoco/browne.cfm.

[18] In 2004 Dupont had revenues of \$27.3 billion and employed 60,000 people.

REFERENCES

Antonelli, Angela, Schaefer, Brett D., and Annett, Alex: 1997, *The Road to Kyoto: How the Global Climate Treaty Fosters Economic Impoverishment and Endangers U.S. Security* Heritage Foundation Backgrounder #1143. [online] http://www.heritage.org/Research/PoliticalPhilosophy/BG1143.cfm, accessed January 2006.

Bailie, Alison, Bernow, Stephen, Dougherty, William, and Lazarus, Michael: 2003, *Analysis of the Climate Stewardship Act: A Study for the Natural Resources Defense Council*, Tellus Institute, Boston, MA.

Berman, E. and Bui, L.T.M.: 2001, "Environmental Regulation and Productivity: Evidence from Oil Refineries". *Review of Economics & Statistics* 83(3): 498–510.

Bernow, Stephen, Rudkevich, Alexandr, Ruth, Michael, and Peters Irene: 1998, *A Pragmatic CGE Model for Assessing the Influence of Model Structure and Assumptions in Climate Change Policy Analysis*, A Report to the Office of Air and Radiation, Office of Atmospheric Programs, U.S. EPA, Tellus Institute Study #96-190, Boston, MA.

Bernow, Stephen, Cory, Karlynn, Dougherty, William, Duckworth, Max, Kartha, Sivan, Ruth, Michael, and Goldberg, Marshall: 1999, *America's Global Warming Solutions*, Tellus Institute study for the World Wildlife Fund and Energy Foundation, [online] http://www.tellus.org/energy/publications/solution.pdf, accessed December 2005.

Brown, Marilyn A., Levine, Mark D., Short, Walter, and Koomey, Jonathan G.: 2001, "Scenarios for a Clean Energy Future," *Energy Policy* 29(14): 1179–1196.

Brown, M.A., Antes, M., Franchuk, C., Koske, B.H, Michaels, G., and Pellegrino, J.: 2006, *Results of the Technical Review of the Climate Change Technology Program's R&D Portfolio*, Oak Ridge National Laboratory, Oak Ridge, TN [online] http://www.ornl.gov/sci/eere/communications.htm, accessed July 2006.

Burtraw, Dallas, Evans, David, Krupnick, Alan, Palmer, Karen, and Toth, Russell: 2005, "Economics of Pollution Trading for SO_2 and NO_x, *Annual Review of Environmental Resources* 30: 253–289.

[CBO] Congressional Budget Office: 2005, "Macroeconomic and Budgetary Effects of Hurricanes Katrina and Rita," Statement before the Committee on the Budget, U.S. House of Representatives by Douglas Holz-Eakin, Director Congressional Budget Office, [online] http://www.cbo.gov/ftpdocs/66xx/doc6684/10-06-Hurricanes.pdf, accessed March 2006.

[CCTP] U.S. Climate Change Technology Program: 2005, *Strategic Plan Draft for Public Comment*, September, [online] http://www.climatetechnology.gov/stratplan/draft/index.htm accessed July 2006.

Columbia University: 2005, "What are the Projected Costs of Climate Change in the Region's Coastal Communities and Coastal Environments?" Climate Change Information Resources New York Metropolitan Region, [online] http://ccir.ciesin.columbia.edu/nyc/ccir-ny_q2e.html, accessed January 2006.

Crossett, K., Culliton, T., Wiley, P., and Goodspeed, T.: 2004, *Population trends Along the Coastal United States*, National Oceanic Atmospheric Administration. [online] http://oceanservice.noaa.gov/programs/mb/pdfs/coastal_pop_trends_complete.pdf, accessed March 29, 2006.

[EC] European Commission: 2005, *Communication from the Commission: Further Guidance on Allocation Plans for the 2008–2012 Trading Period of the E.U. Emissions Trading Scheme*, [online] http://ec.europa.eu/environment/climat/pdf/nap_2_guidance_en.pdf, accessed November 2005.

[EC] European Commission: 2006, *Greenhouse Gas Monitoring and Reporting. "Climate Change: EU on Track to Reach Kyoto Targets, Latest Projections Show*, European Commission – Environment, [online] http://ec.europa.eu/environment/climat/gge_press.htm, accessed June 3, 2006.

Edmonds, Jae, Scott, Michael, Roop, Joseph, and MacCracken, Christopher: 1999, *International Emissions Trading and Global Climate Change*, Pew Center on Global Climate Change, Arlington, VA.

[EEA] European Environment Agency: 2004, Impacts of Europe's Changing Climate, Report No 2/2004, [online] http://reports.eea.europa.eu/climate_report_2_2004/en, accessed June 7, 2006.

[EIA] Energy Information Administration: 1998, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, Energy Information Administration Office of Integrated Analysis and Forecasting, [online] http://www.eia.doe.gov/oiaf/kyoto/pdf/sroiaf9803.pdf, accessed November 2005.

[EIA] Energy Information Administration: 2003a, *Analysis of Senate Amendment 2028, The Climate Stewardship Act of 2003*, [online] http://www.eia.doe.gov/oiaf/analysispaper/ sacsa/pdf/ s139amend_analysis.pdf, accessed January 2006.

[EIA] Energy Information Administration: 2004, *Annual Energy Outlook*, [online] http://www.eia.doe.gov/oiaf/archive/aeo03/index.html, accessed October 2005.

Ellerman, Denny, Joskow, Paul L., Schmalensee, Richard, Montero, Juan-Pablo, and Bailey, Elizabeth M.: 2000, *Markets for Clean Air: The U.S. Acid Rain Program*, Cambridge University Press, New York, NY.

Ellerman, Denny, Joskow, Paul L., and Harrison, David: 2003, *Emissions Trading in the U.S. Experience, Lessons and Considerations for Greenhouse Gases*, Pew Center on Global Climate Change, Arlington, VA.

[ELI] Environmental Law Institute: 1997, *Implementing an Emissions Cap and Allowance Trading System for Greenhouse Gases: Lessons from the Acid Rain Program*, Environmental Law Institute, Washington, DC.

Emanuel, Kerry: 2005, "Increasing Destructiveness of Tropical Cyclones Over the Past 30 years," *Nature* 436: 686–688.

Goodstein, Eban and Hodges, Hart: 1997, "Polluted Data," *The American Prospect* 35 November–December, 64–69.

Goulder, Laurence: 2004, *Induced Technological Change and Climate Policy*, Pew Center on Global Climate Change, Arlington, VA.

Hanemann, Michael and Farrell, Alex (Project Directors): 2006, "Managing Greenhouse Gas Emissions in California," The California Climate Change Center at UC Berkeley, [online] http://calclimate.berkeley.edu/managing_GHGs_in_CA.html, accessed January 2006.

Hansen, James, Naarenko, Larissa, Ruedy, Reto, Sato, Makiko, Willis, Josh, Del Genio, Anthony, Koch, Dorothy, Lacis, Andrew, Low, Ken, Menon, Surabi, Novakov, Tica, Perliwitz, Judith, Russell, Gary, Schmidt, Gavin, and Tausnev, Nicolas: 2005, "Earth's Energy Imbalance: Confirmation and Implications " *Science* Vol. 308, June, 1431–1435.

Harrington, Winston, Morgenstern, Richard D., and Nelson, Peter: 2000, "On the Accuracy of Regulatory Cost Estimates," *Journal of Policy Analysis and Management* Spring, 19(2): 297–322.

[IPCC] Intergovernmental Panel on Climate Change: 2001a, "Climate Change 2001: The Scientific Basis," Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Press, New York, NY.

[IPCC] Intergovernmental Panel on Climate Change: 2001b, "Climate Change 2001: Synthesis Report," in R.T. Watson and the Core Writing Team (eds) *A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom, and New York, NY.

Jaffe, Adam, Peterson, Steven R., Portney, Paul R., and Stavins, Robert N.: 1995, "Environmental Regulation and the Competitiveness of US Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature* 33(1): 132–63.

Jeppesen, Tim, List, John, and Folmer, Henk: 2002, "Environmental Regulations and New Plant Locations Decisions: Evidence from a Meta-Analysis," *Journal of Regional Science* 42(1): 19.

Jorgenson, Dale and Goettles, Richard: 2004, *U.S. Market Consequences of Global Climate Change*, Pew Center on Global Climate Change, Arlington, VA.

Kleypas, J.A., Feely, R.A., Fabry, V.J., Langdon, C., Sabine, C.L., and Robbins, L.L.: 2005, *Impacts of Ocean Acidification on Coral Reefs and other Marine Calcifiers: A Guide for Future Research*, A report from a workshop sponsored by the National Science Foundation, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey, [online] http://www.ucar.edu/communications/Final_acidification.pdf, accessed July 2006.

Lempert, Robert: 2002, *Capital Cycles and the Timing of Climate Change Mitigation Policy*, Pew Center on Global Climate Change, Arlington, VA.

Meinshausen, Malte: 2006, "What does a 2 Degree Celsius Target Mean for Greenhouse Gas Concentrations? A brief Analysis Based on Multi-Gas Emission pathways and Several Climate Sensitivity Uncertainty Estimates," in Hans Joachim Schellnhuber, Wolfgand Cramer, Nebojsa Nakcenovic, Tom Wigley and Gary Yohe (eds) *Avoiding Dangerous Climate Change*, Cambridge Press, UK, pp.265–279.

Michaels, Patrick: 2002, "Global Warming and the Kyoto Protocol: Paper Tiger, Economic Dragon," American Legislative Exchange Council, [online] http://www.alec.org/meSWFiles/pdf/0208.pdf, accessed January 2006.

[NCEP] National Commission on Energy Policy: 2004, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges*, [online] http://www.energycommission.org/files/contentFiles/report_noninteractive_44566feaabc5d.pdf, accessed July 9, 2006.

[NRC] National Research Council: 2002, *Abrupt Climate Change: Inevitable Surprises*, National Research Council. National Academies Press, [online] http://fermat.nap.edu/catalog/10136.html, accessed July 9, 2006.

Oak Ridge National Laboratory: 2004, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, USA, [online] http://cdiac.esd.ornl.gov, accessed July 9, 2006.

Paltsev, Sergey, Reilly, John, Jacoby, Henry, Ellerman, Denny, and Tay, Kok Hou: 2003, *Emissions Trading to Reduce Greenhouse Gas Emissions in the United States: The McCain-Lieberman Proposal*, MIT Joint Program on the Science and Policy of Global Change. Report #97, [online] http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt97.pdf, accessed November 2005.

Porter, Michael and van der Linde, C.: 1995a, "Toward a New Conception of the Environment-Competitiveness Relationship," *Journal of Economic Competitiveness* 9(4): 97–118.

Porter, Michael and van der Linde, C.: 1995b, "Green and Competitive," *The Harvard Business Review*, September–October, 120–134.

Preston, B.L. and Jones, R.N., 2006, "Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions," Commonwealth Scientific and Industrial Research Organisation (CSIRO), Prepared for the Australian Business Roundtable on Climate Change, [online] http://www.csiro.au/csiro/content/file/pfbg,,.html, accessed July 9, 2006.

Reilly, John, Jacoby, Henry, and Prinn, Ronald: 2003, *Multi-Gas Contributors to Global Climate Change: Climate Impacts and Mitigation Costs of Non-*CO_2 *Gases*. Pew Center on Global Climate Change, Arlington, Virginia.

Repetto, Robert, Maurer, Crescencia, and Bird, Garren: 1997, U.S. Competitiveness is Not at Risk in the Climate Negotiations, U.S. Climate Notes, [online] www.wri.org/cpi/notes/comp-us.html, accessed January, 2006.

Rignot, E. and Kanagaratnam, P.: 2006, "Changes in the velocity structure of the Greenland Ice Sheet," *Science* 311: 986–990.

Schellnhuber, Hans Joachim, Cramer, Wolfgand, Nakcenovic, Nebojsa, Wigley, Tom, and Yohe, Gary (eds): 2006, *Avoiding Dangerous Climate Change*, Cambridge Press, UK.

Smith, Anne E., Bernstein, Paul, and Montgomery, W. David: 2003, The Full Costs of S.139, With and Without its Phase II Requirements, Charles Rivers Associates, [online] http://www.crai.com/pubs/pub_3694.pdf, accessed November 2005.

Smith, Joel B: 2004, *A Synthesis of Potential Climate Change Impacts on the U.S.*, Pew Center on Global Climate Change, Arlington, VA.

Thorning, Margo: 2006a, "Can We Afford to Heed Gore," Op-Ed, *Baltimore Sun*, [online], http://www.accf.org/pdf/053006_BaltSun_GW.pdf, accessed July 9, 2006.

Thorning, Margo: 2006b, Testimony before the U.S. Senate Committee on Energy and natural Resources on "Design Elements of a Mandatory Market Based Greenhouse Gas Regulatory System," Climate Change Conference April 4, 2006, [online] http://energy.senate.gov/public/_files/panel2.pdf, accessed July 9, 2006.

Thorning, Margo: 2006c, "California Climate Change Policy: Is AB 32 a Cost-Effective Approach?" American Council for Capital Formation, [online] http://www.accf.org/pdf/Analysis061406.pdf, accessed June 16, 2006.

[UNFCC] United Nations Framework on Climate Change: 1992, [online] http://unfccc.int/resource/docs/convkp/conveng.pdf, accessed November 2005.

Velicogna, Isabella and Wahr, John: 2006, Measurements of Time-Variable Gravity Show Mass Loss in Antarctica *Science* Vol 311: 1754–1756.

Webster, P.J., Holland, G.J., Curry, J.A., and Chang, H.-R.: 2005, "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment," *Science* 16 September: 1844–1846.

[WEFA] Wharton Econometric Forecasting Associates: 2002, "Kyoto Protocol and Beyond" The High Economic Cost to the United States," Prepared for the American Council for Capital Formation by DRI-WEFA, [online] http://www.accf.org/pdf/EcoImpact-GHG-US.PDF, accessed January 2006.

Weyant, J.P., Davidson, O., Dowlatabadi, H., Edmonds, J., Grubb, M., Parson, E.A., Richels, R., Rotmans, J., Shukla, Pr., and Tol, R.S.J.: 1996, "Integrated Assessment of Climate Change: An Overview and Comparison of Approaches and Results," in J.P. Bruce, H. Lee, and E.F. Haites (eds) Chapter 10 in *Climate Change 1995: Economic and Social Dimensions of Climate Change*, Cambridge University Press, New York, NY.

Weyant, John: 2000, *An Introduction to the Economics of Climate Change Policy*, Pew Center on Global Climate Change, Arlington, VA.

Whitehouse: 2002, "President Announces Clear Skies & Global Climate Change Initiatives," [online] http://usgovinfo.about.com/gi/dynamic/offsite.htm?site=http://www.whitehouse.gov/news/releases/2002/02/20020214%2D5.html, accessed June 2, 2006.

World Bank: 2004, "World Development Indicators 2004," [online] http://web.worldbank.org/wbsite/external/datastatistics, accessed July 26, 2005.

CHAPTER 14

ENERGY MYTH THIRTEEN – DEVELOPING COUNTRIES ARE NOT DOING THEIR PART IN RESPONDING TO CONCERNS ABOUT CLIMATE CHANGE

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One of the most persistent controversies about energy-related climate change mitigation policies and actions by "developed" countries is whether they make sense without analogous actions by rapidly growing developing country economies. Embedded in this controversy is a myth that developing countries are not doing enough without their agreement to mandatory emission reduction targets, and that global action is futile until they agree to do more.

This view underlies such statements as the following:

> Any agreement that allows the developing countries to continue emitting greenhouse gases would in effect negate the efforts of those countries that are trying to reduce them. It would drastically increase the cost of gasoline, electricity, and fuel oil for Americans and cause significant harm to the U.S. economy. (Heritage Foundation, 2001; also see American Council for Capital Formation, 2000)
>
> The United States has taken a firm position that "meaningful" participation of developing countries in commitments made in the (Kyoto) protocol is critical both to achieving the goals of the treaty and to its approval by the U.S. Senate…The U.S. government also argued that success in dealing with the issue of climate change and global warming would require such participation.
> (Congressional Research Service, 2000)

This chapter explains why such a myth – that developing countries are proceeding to emit greenhouse gases without any significant sensitivity to implications for the global climate – is not entirely, or even largely, true. First, it considers the issue of what level of contribution by developing countries could be considered "enough." It then briefly describes a range of international agreements related to developing country roles; summarizes a variety of significant voluntary responses by developing countries, generally in the absence of government-to-government international agreements; and considers how these voluntary actions can serve as starting points toward larger roles in the future.

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 341–350

14.1. WHAT IS THE DEVELOPING COUNTRY PART OF A GLOBAL RESPONSE?

Whether or not developing countries are doing their part in stabilizing greenhouse gas (GHG) concentrations in the earth's atmosphere depends considerably on a determination of what their part should be. One perspective is that *those who caused the problem should fix it.* In other words, because increases in concentrations of GHG in the earth's atmosphere due to fossil energy use were caused very largely by activities in the industrialized world, especially Europe and North America, and because these activities created wealth in those areas, the areas which benefited should carry the responsibility of dealing with the environmental consequences. A different perspective is that, regardless of the past, *all those who threaten problems in the future must be involved in fixing it.* In other words, contributions to stabilizing GHG emissions in the future must reflect future emissions, where the share of the global total from developing countries is already beginning to exceed the share from the traditional industrialized countries.

To a considerable degree, this difference in perspective is rooted in differences between an emphasis on equity/justice and an emphasis on reality/pragmatism. In many cases, advocates of one emphasis fail to see merit in the other, while policy discussions face a need to develop approaches that recognize both imperatives.

Consider first the equity perspective. To the degree that climate change is predominantly the result of human activities that convert fossil carbon fuels into greenhouse gas emissions, which is widely accepted if not universally agreed (IPCC, 2001), there is no question whatsoever whose emissions since the birth of the Industrial Revolution, and especially whose emissions since the middle of the 20th Century, are the cause. The problem has been caused by fossil fuel consumption in what are usually called developed or industrialized countries: mainly the United States, Western Europe, and other advanced economies such as Japan. This consumption and the energy services that it has enabled have supported high incomes and standards of living, in many cases increasing gaps between the "North," or the developed countries, and the "South," or the developing countries. The main exception is the oil and natural gas producing countries in what was traditionally classified as the South, whose standards of living have often benefited from a "natural resource lottery" (Haggett, 1975, pp. 460–61) that makes them providers of fossil fuels to feed appetites in developed countries.

Globally, since 1751 a little more than 300 billion tons of carbon have been released to the earth's atmosphere from the consumption of fossil fuels (along with cement production). Half of these emissions have occurred since the mid-1970s. Until the 1990s, a very large proportion of the emissions were from the United States, Europe, Japan, Canada, and Australia: the relatively affluent, relatively large developed countries of the world. In 2003, the United States still accounted for more than 22% of total global carbon dioxide emissions, expressed in tons of carbon (Marland *et al.*, 2006).

Data on *per capita* CO_2 emission rates show greater contrasts between developed and less developed countries. For instance, the U.S. figure in 2003 was 5.43 metric tons of carbon emitted per capita, compared with 0.86 for China, 0.33 for India, and 0.1 for Ghana (Marland *et al.*, 2006). Per capita carbon emissions tend to be closely correlated with per capita national incomes (although the correlations are higher between high and low values than in the middle ranges (Baumert *et al.*, 2005), and developing countries generally argue that the equitable metric for emission reduction responsibilities should therefore be per capita emissions rather than national total emissions.

Further, they argue that they have a right to close the gap between developed and developing countries by pursing economic development and growth, which requires significant increases in the consumption of energy services. If the most affordable energy pathways involve fossil fuels, then caps on their greenhouse gas emissions mean caps on their economic development. In other words, developing country roles in mitigating global trends in greenhouse gas emissions should not only be framed by the fact that they did not cause the problem but also by the fact that their development goals are a higher priority.

At the same time, many observers and policymakers suggest that, regardless of equity and justice, those who caused the climate change problem cannot by themselves solve it; so the entire global community must be involved. In terms of total national carbon emissions, China is now the second largest country, India the fourth, Korea the ninth, and Mexico the eleventh (Marland *et al.*, 2006). And emissions from large, growing economies in the developing world are growing more rapidly than in the developed world; current projections are that carbon emissions from the developing countries as a group will pass the industrialized countries as a group before 2020 (Figure 14.1). As a result, substantial emission reductions by developed countries will almost certainly not be enough to stabilize concentra-

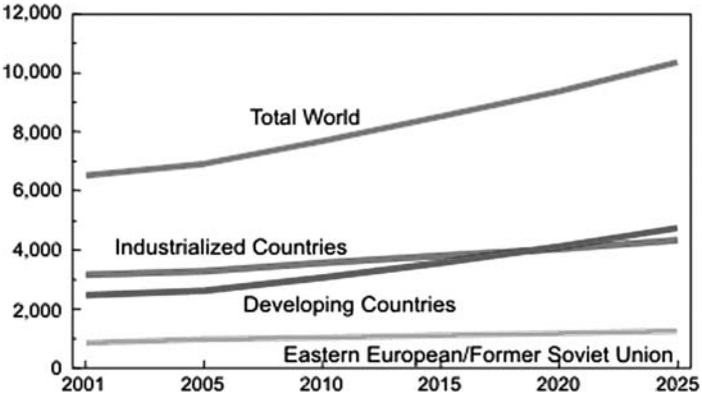

Figure 14.1. World Carbon Dioxide emissions by region, 2001–2025 (Million Metric Tons of Carbon Equivalent) (EIA, 2003b)

tions of greenhouse gases in the earth's atmosphere; developing country roles will have to be substantial if the global carbon cycle is to be stabilized. The fact is that both of these perspectives are valid. To summarize, those who played major roles in causing the problem and have benefited from the causal activities have a special responsibility for showing leadership in addressing the problem. To do less is to be irresponsible. But the developed countries whose GHG emissions have driven increasing GHG concentrations in the earth's atmosphere over the past century cannot solve the problem by reducing their own emissions. Emission trends in relatively large, rapidly growing developing countries will dominate global totals over the next half-century or more, regardless of what developed countries do; therefore, actions by developing countries are an unavoidable key to the global response. The challenge is to find a policy pathway that finds a politically acceptable and environmentally responsible balance between the two perspectives.

14.2. WHAT IS THE CURRENT POLICY CONTEXT FOR DEVELOPING COUNTRY PARTICIPATION?

Discussions of developing country roles in atmospheric greenhouse gas stabilization are rooted in a number of international and other governmental initiatives – while a great many activities are emerging independent of those initiatives.

The dominant institutional paradigm is the United Nations Framework Convention on Climate Change (UNFCCC), one of several agreements emerging from the 1992 UN Conference on Environment and Development in Rio de Janeiro – 25 years after the UN Conference on the Human Environment in Stockholm, which introduced the concept of intergenerational equity in managing the earth's environment.

UNFCCC operates through annual meetings of the Conference of Parties (COPs), the countries who are parties to the convention. The best-known product has been the Kyoto Protocol to the UNFCCC, fashioned at COP-3 in 1997: an international treaty intended to stabilize greenhouse gases in the environment at a level that would prevent dangerous interference with the world's climate system. The Kyoto Protocol focuses on Annex I countries, which accounted for at least 55% of total global carbon dioxide emissions in 1990. Annex I countries that ratify the treaty commit themselves to reduce their emissions of greenhouse gases compared with 1990 levels and/or to engage in emissions trading to achieve equivalent net global reductions in emissions.

Although it is the most familiar, the Kyoto Protocol is not the only mechanism incorporated within UNFCCC. Article 12 of the convention calls for periodic reports from countries that are parties to UNFCCC on steps they are taking to implement the general agreement. Since parties to the UNFCCC extend well beyond the Annex I countries, this includes a large number of developing countries; and in many cases reports from developing countries have been professional and perceptive. In addition, the annual COP meetings continue the process of intergovernmental discussions about climate change response policies and measures, and the periodic reports of the Intergovernmental Panel on Climate Change (IPCC) provide summaries of the knowledge base about climate change itself, impacts and adaptation potentials, and mitigation alternatives.

Elsewhere in the United Nations, such bodies as the UN Environment Programme and the UN Commission on Sustainable Development (CSD) are also concerned with climate change responses as aspects of sustainable global and national development. Other multilateral bodies contribute support as well, such as the Global Environment Facility (GEF), established in 1991 to help developing countries support projects that contribute to protecting the global environment; an example has been a major project on Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AIACC), which between 2002 and 2005 supported locally-conducted assessments in several developing regions.

As one of the few developed countries which have not ratified the Kyoto Protocol, the United States has been under pressure to show that it is prepared to contribute to global climate change responses in other ways. Current initiatives are many and diverse, including energy technology research and development to enlarge the range of carbon emission reducing technology options. Multi-lateral partnerships for science and technology cooperation include a Carbon Sequestration Leadership Forum with 19 international members, an International Partnership for the Hydrogen Economy with 17 international members, a nuclear energy Generation IV International Forum with 11 members, a Methane to Markets program with 16 members, and a fusion energy partnership called ITER. Beyond such science and technology-oriented partnerships, U.S. initiatives have included the Clean Energy Initiative (CEI), a Presidential Initiative announced at the 2002 World Summit on Sustainable Development, and the Asian Pacific Partnership on Clean Development and Climate. Other relevant activities include U.S. participation in the Asia Pacific Economic Cooperation (APEC) forum and the Millennium Challenge Corporation, which links development assistance to government performance.

Other developed countries have climate change related initiatives that relate to developing countries as well, which means that *the landscape is rich with structures for considering developing country roles in the global response to concerns about climate change, beyond the Kyoto protocol alone* – and for considering responsibilities of developed countries to provide energy alternatives for developing countries that can help to meet their energy needs for development without adding to emission trends that are driving climate change. Focusing on developing country roles in the Kyoto Protocol misses the point.

14.3. WHAT ARE DEVELOPING COUNTRIES DOING IN RESPONSE TO CONCERNS ABOUT CLIMATE CHANGE?

Although developing countries have not agreed to target levels of GHG emission reductions (like some developed countries, including the United States), in many cases they are notably active in responding to concerns about climate change, even if their motivations are often related to other benefits for their sustainable development. In some cases, in fact, they are global leaders in demonstrating important clean energy alternatives and considering adaptation as an aspect of an integrated response to likely climate changes.

The most prominent example is Brazil, a large developing country: the only country in the world containing a substantial industrial sector that is deriving a majority of its energy from renewable sources. To a considerable degree, this is because of the country's abundant potential for hydroelectric energy production, combined with decisions in the 1970s and 1980s to undertake very large hydropower projects, such as the Itaipu and Tucurui dams. Today, Brazil depends on hydroelectric power for more than 80% of its electric power generation. But it also reflects such decisions as to push the conventional boundaries on liquid fuel production from biomass: in their case, ethanol production from their sugar industry. As of June 2003, national gasoline supplies included 25% ethanol, and the entire national highway vehicle fleet was to be capable of running on both gasoline and ethanol by 2006 (EIA, 2003a). As a result, although Brazil consumes 2.2% of the world's total energy, it accounts for only 1.5% of total global energy-related carbon emissions. No developed country can match this record, although Brazil's large-scale development of hydropower and biomass energy has had other environmental implications than carbon emission reductions alone, not all of them positive.

Other examples of leadership are too numerous to list. Significant examples include:

- *China's achievements in industrial energy efficiency improvement.* Between 1997 and 2000, China's national energy consumption dropped more than 9% while total national GDP continued to increase (Lewis *et al.*, 2003). Nearly all of this change was the result of reductions of energy consumption in industry while industrial production continued to grow. Although total energy consumption has increased since 2000, this emission reduction accomplishment in the late 1990s is virtually unprecedented in the midst of development in a large economy, especially at China's stage in the development process.
- *India's achievements in replacing petroleum-based highway vehicle fuels with alternative fuels.* In 1998, in response to a suit brought by environmental protection advocates, the Indian Supreme Court mandated that the public vehicle fleet in the capitol city of New Delhi be converted to Compressed Natural Gas (CNG), the most dramatic change in highway fuel use in any world city in history. By 2002, the transformation was largely complete, with visible improvements in urban air quality (Bose and Sperling, 2002; Jalihal and Reddy, 2006). This grand experiment remains a unique example of rapid movement from conventional highway fuels to emission-reducing alternative fuels. India has also been a world leader in electric power plant rehabilitation to improve efficiencies and reduce emissions.
- *Achievements of Barbados in solar water heating.* Perhaps the only developing country to be a hemispheric leader in a clean energy technology (other than Brazil's large-scale applications) is Barbados, which ranks with Israel and Cyprus as a producer and user of solar water heaters. In this small country, about 32,000 solar water heaters are in use in homes, commercial buildings, and hotels,

including about one-third of all households – easily the most extensive such use in the Western Hemisphere. Three small production and service firms are moving into regional and in some cases global markets as suppliers of solar water heaters, the only major world supplier from the Western Hemisphere, a remarkable case of payoffs from local leadership three decades ago (Perlack and Hinds, 2004).

- *Proactive cooperation of Central American countries in agreements to offset carbon emissions in developed countries by carbon sink enhancements or emission improvements in developing countries.* Predating the Kyoto Protocol, a UNFCCC initiative called Activities Implemented Jointly (AIJ) – under Kyoto renamed Joint Implementation (JI) – encouraged such agreements. Worldwide, the successes were limited; but among the most enthusiastic of the international partners in pursuing opportunities for emission reduction were Central American countries: e.g., agreements between U.S. electric utilities and afforestation projects in Costa Rica.

In each of these cases, accomplishments by a developing country in not only exploring global greenhouse emissions but also producing measurable reductions in such emissions were anchored not in international climate change agreements but in national, regional, or local economic and/or environmental co-benefits. Reductions in greenhouse gas emissions were motivated by cost savings (as in China's industrial sector or India's power plants), by local and regional air quality improvements (as in India's CNG use), or by sustainable development opportunities (as in Barbados's solar water heating and Central America's JI cooperation). Climate change benefits were noted and reported with pride, but other benefits – more direct and near-term – were the reasons for action.

Meanwhile, on the international stage, developing countries have been showing leadership in another important connection. At the Eighth meeting of the UNFCCC Conference of Parties (COP-8) in New Delhi in 2002, developing countries led a successful effort to expand international responses to climate change to include *adaptation* as well as *mitigation*. Anchored once again in their own development concerns, in this case about their own vulnerabilities to impacts of climate change, they catalyzed the development of a Delhi Ministerial Declaration on Climate Change and Sustainable Development (usually called "The Delhi Declaration"), which called for urgent action to advance adaptation measures. Since that time, the UNFCCC has directed that attention to national adaptation programs of action be added to national communications, especially from the least-developed countries, and many developing countries (including China and India) have ratified the Kyoto Protocol. Discussions continue at the annual COP meetings about how to incorporate commitments to supporting adaptation in future climate change policies and treaties. Early analysis indicates that results of cost-benefit comparisons are scale-dependent, which has important policy implications. The net benefits of adaptation are greatest at the local scale, while the net benefits of avoidance are greatest at the global scale (Figure 14.2).

This record, of course, does not add up to a substantial overall response by developing countries to concerns about global climate change. In fact, some of the oil-exporting developing countries are among the most vocal skeptics about risks

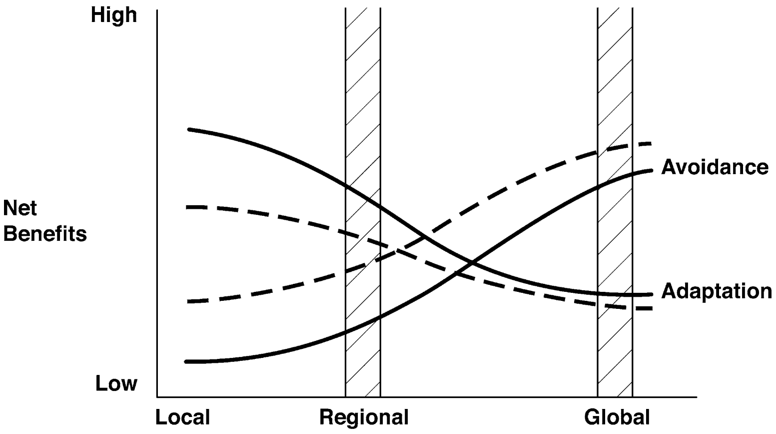

Figure 14.2. The scale dependence of net benefits from avoidance and adaptation strategies (The solid line depicts moderate climate change; the dotted line depicts more substantial climate change, Adapted from Wilbanks, 2003)

from climate change. But in a period where developed countries themselves have shown little appetite for significant actions to reduce carbon emissions – with parts of Europe as the exception – developing countries do appear to be doing their part in what still remains a diverse, scattered, partial global response. Seen in the aggregate, their contributions have not been transformative, but neither have been the contributions from developed countries.

This early experimentation seems to suggest several general conclusions to date:

- Interests on the part of developing countries in contributing to greenhouse gas emission mitigation depend on economic or environmental co-benefits and/or on concerns about possible vulnerabilities to climate change impacts in their own areas, not on a strong commitment to mitigation per se.
- In a number of cases, often through bottom-up distributed initiatives rather than national policy or action, developing countries are not only responding but leading the global response, because so often the co-benefits are considerable.
- Even though many observers believe that adaptation is more likely to be able to address many climate change risks and costs in developed regions than in developing regions, developing countries are ahead of most developed countries in considering this aspect of an integrated portfolio of responses to climate change.

14.4. WHAT DOES THE CURRENT PATTERN OF RESPONSE IMPLY FOR FUTURE POLICY?

These developing country responses add up to a pattern of response that is important for two reasons. First, it is evidence that in some cases developing countries are doing what might be considered even more than their part. Second, it suggests possible pathways for increasing the developing country contribution in ways that can be equitable as well as practical, related directly to the self-interest of those countries. In effect, the starting point in expanding developing country roles is to pay attention to what makes sense for them – and how developed countries can assist them with their sustainable development in ways that *also* help to stabilize greenhouse gas concentrations in the earth's atmosphere.

For instance, an important motivation for developing country roles in addressing concerns about climate change is a perception on their part that they are vulnerable to impacts of climate change. Accordingly, a high priority is to assist developing countries in improving their own capacities to project and assess relatively localized climate change. The greater their capacity to explore their own vulnerabilities, rather than relying on projections by others, the greater the likelihood that they will appreciate the value of effective responses – globally, nationally, and locally.

A second element of developing country responses is having an array of technology and policy options for them to consider (AAG, 2003). One of the most powerful ways for developed countries to encourage developing country contributions to climate change responses is to develop and demonstrate technologies and policies that deliver benefits for limiting climate change impacts (through greenhouse emission reduction and/or human and natural system adaptation) and also for sustainable development. Limitations of current major energy technology options are a particularly big hurdle. Consider a developing country energy decision-maker who says: You don't want us to use our coal, right? And you don't want us to buy a lot more oil, right? And you don't want us to move aggressively into nuclear energy, right? And you don't want us to build big dams for hydropower, or cut down our forests for energy from biomass? And you don't yourselves use other forms of renewable energy as a major part of your energy supply mix, because they are either too small or too expensive? What do you expect us to do? Either develop something better or get out of our way. . .As a part of their responsibility for causing the problem, the developed countries should be creating robust, affordable options for meeting growing energy needs in developing countries while at the same time reducing carbon emissions from energy supply systems.

Third, it is worth taking very seriously the concerns of developing countries about adaptation. We know that the stabilization level for GHG in the earth's atmosphere which avoids "dangerous impacts" is higher for an adaptable world; mitigation and adaptation are complements, not competitors (Wilbanks *et al*, 2006). "Kyoto II" is likely to consider credit for adaptation investments, at least in vulnerable developing countries, as well as mitigation investments. A major part of the responsibility of developed countries for fixing the problem, in fact, is fixing problems with climate change *consequences* as well as with *causes*. It is important – in some cases, urgently important (e.g., in the Arctic: ACIA, 2004) – to examine how adaptation can be facilitated and supported, in both developing and developed countries, and to understand limits and costs of adaptation as well as potentials in order to inform many complex decisions and policies in the future.

In these kinds of ways, seeing value and information in developing country responses to date to climate change concerns is critically important to us all. Rather than assuming that they are not doing their part, we should be learning what their own actions tell us about how to expand their roles in a spirit of partnership and mutual self-interest.

REFERENCES

[AAG] Association of American Geographers: 2003, *Global Change and Local Places: Estimating, Understanding, and Reducing Greenhouse Gases*, in R. Kates, T. Wilbanks, and R. Abler (eds), Cambridge University Press, Cambridge, MA, USA.

[ACIA] Artic Climate Impact Assessment: 2004, *Impacts of a Warming Arctic*, Cambridge University Press, Cambridge, MA, USA.

American Council for Capital Formation: 2000, "A U.S. Perspective on the Economic Impact of Climate Change Policy," *Special Report*, Margo Thorning, Center for Policy Research, [online] www.accf.org/publications/reports/sr-us-perspective.html, accessed July 21, 2006.

Baumert, K., Herzog, T., and Pershing, J.: 2005, "Navigating the Numbers: Greenhouse Gases and International Climate Change Agreements," World Resource Institute, Washington, DC, USA.

Bose, R. and Sperling, D.: 2002, "Transport in Delhi, India; Environmental Problems and Opportunities," *Transportation Research Record*, 1815, pp. 3–10.

Congressional Research Service: 2000, "Global Climate Change Treaty: The Kyoto Protocol," CRS Report 98-2, updated March 6, 2000, [online] www.ncseonline.org/NLE/CRSreports/Climate/clim-3.cfm, accessed July 21, 2006.

[EIA] Energy Information Administration: 2003a, "Brazil: Environmental Issues," *Country Analysis Briefs*, EIA, Washington, DC, USA.

[EIA] Energy Information Administration: 2003b, *International Energy Outlook, 2003*, Washington, DC, USA.

Haggett, P.: 1975, *Geography: A Modern Synthesis*, 2nd ed., Harper and Row, New York, NY, USA.

Heritage Foundation: 2001, "Why President Bush is Right to Abandon the Kyoto Protocol," Policy Research & Analysis Backgrounder #1437, [online] http://www.heritage.org/Research/ EnergyandEnvironment/BG1437.cfm, accessed July 21, 2006.

[IPCC] Intergovernmental Panel on Climate Change: 2001, *Climate Change 2001: The Scientific Basis*, Cambridge University Press, Cambridge, MA, USA.

Jalihal, S. and Reddy, T.: 2006, "Assessment of the Impact of Improvement Measures on Air Quality: Case Study of Delhi," *Journal of Transportation Engineering* 132, pp. 482–88.

Lewis, J., Fridley, D., Sinton, J., and Lin, J.: 2003, "Sectoral and Geographic Analysis of the Decline in China's National Energy Consumption in the Late 1990s," *Proceedings of the ACEEE Summer Study on Energy Efficiency in Industry, Rye Brook, NY, July 29 – August 1, 2003*, ACEEE, Washington, DC, USA.

Marland, G., Boden, T.A., and Andres, R.J.: 2006, "Global, Regional, and National Fossil Fuel CO_2 Emissions." In *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, USA.

Perlack, R. and Hinds, W.: 2004, "Evaluation Of Renewable Energy Incentives: The Barbados Solar Water Heating Experience," Technical Report Series 2004-1, Renewable Energy Centre, Barbados.

Wilbanks, T.J.: 2003, "Geographic Scaling Issues in Integrated Assessments of Climate Change," in J. Rotmans and D. Rothman (eds), *Scaling Issues in Integrated Assessment*, Swets and Zeitlinger, pp. 5–34.

Wilbanks, T.J., Leiby, P., Perlack, R., Ensminger, J.T., and Wright, S.B.: forthcoming, "Toward an Integrated Analysis of Mitigation and Adaptation: Some Preliminary Findings", in special issue, *Mitigation and Adaptation Strategies for Global Change.*

CHAPTER 15

CONCLUSIONS – REPLACING MYTHS WITH MAXIMS: RETHINKING THE RELATIONSHIP BETWEEN ENERGY AND AMERICAN SOCIETY

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15.1. INTRODUCTION

In his article assessing the proper role of method in the social sciences, L.H.M. Ling (2002) opens with a tale about a fish and a turtle. Once upon a time, Ling begins, there lived a colorful and proud little fish. He had lots of friends and loved the water surrounding him. He swam quickly, swiftly, and gracefully. One day he met a turtle, an old friend whom he had not seen in a long time.

> The fish greeted the turtle and said, “Hello, Sister Turtle, how are you? I have not seen you in a long time. Where have you been?”
> The turtle replied, “I am fine, thank you for asking. I was away on earth for an errand.”
> “Oh, really? What is earth? Is there something beyond this lovely water?”
> “Very much so.”
> “What does it look like?”
> The turtle paused. It was difficult to find the right words to describe something that the fish had never experienced or seen. But the impatient fish interrupted the turtle’s thoughts.
> “Is the earth like water?”
> “Uh, no…”
> “Can you swim in it?”
> “No.”
> “Do you feel pressure as you go deeper?”
> “No, it’s not like that at all…”
> “Does it dance with sparkling lights when the sun shines on it?”
> “No, not really…”

Impatient, the fish got mad. “I have asked you many questions about earth, and all that you can answer is no. As far as I am concerned, that earth of yours does not exist.”

B.K. Sovacool and M.A. Brown (eds.), Energy and American Society – Thirteen Myths, 351–366

And with that, the disdainful and deeply disappointed fish swam away.

The turtle sighed. “How can one know something *new* when one’s questions are based on the prejudices of the *old*?”

While obviously false – turtles and fish have not yet learned to speak in English – Ling’s narrative reminds us of three important points. First, inhabitants of the same place can hold greatly variable views; they hold distinct values and beliefs, and adhere to often competing interests and motives. As a result, for example, wind farms are attractive landscape features to some and visual eyesores to others.

Second, the tale reminds us that it is difficult to be critical and objective about something that we are a part of. All of us – whether we like it or not – are embroiled in a set of our own deeply held cultural assumptions. Sociologists Emile Durkheim and Marcel Mauss (1963) compared the study of other cultures to a blind person learning to see for the first time. Before given sight, a blind person does not observe the phenomenal world around us that everyone accepts as normal. Initially, when they begin to see they are confronted by chaos, forms, colors and vague visual impressions. Only very slowly and with intense effort can they learn to manage stimuli, create order out of the chaos, distinguish and classify objects.

Similarly, our own culture is as much a part of us as our physical senses. Since it is taken for granted and invisible, it can be extremely difficult to evaluate in any objective sense. Criticism of our culture, furthermore, smacks of condescension and judgment. When confronted with such criticism, most people – like the fish – merely want to swim away. Our thoroughly entrenched social systems, Anthony Giddens once said, “are like the walls of a room from which an individual cannot escape but inside which he or she is able to move around at will” (Pickering, 1993, p. 583).

Third, the story explains why conversations between people holding sharply different views often turn out to be very difficult. In his study assessing the history of science, Thomas Kuhn used the term *incommensurability* to describe the way that insurmountable communication barriers seemed to prevent different groups of scientists from talking to each other in coherent and meaningful ways. Indeed, philosophers such as Ludwig Fleck (1979), Thomas Kuhn (1962, 1977), and Derek de Sola Price (1966) have long argued that different groups of people promote and believe in different cultural practices through “thought collectives,” “paradigms,” and “invisible colleges.” Attempting to communicate to such people from the outside can be akin to speaking to someone in a foreign language they simply don’t understand.

When applied to energy policy, the narrative suggests that analysts and scholars should never forget that the expectations, experiences, and levels of knowledge within a given part of society will always differ. Energy analysis is always encumbered by a certain number of fundamental assumptions. At the same time, heterogeneity of ideas often enriches perspectives, and operating at the nexus of diversity frequently leads to significant breakthroughs in understanding. As this book has attempted to show, the world of energy policy is no stranger to competing values, beliefs, and interpretations.

15.2. UNCERTAINTY, ENERGY POLICY, AND THE FUTURE

As a case in point that dueling interests and opinions populate energy analysis, consider the historical development of energy forecasting. In their broad assessment of energy policy going back to the 1940s, sociologists Eugene A. Rosa et al. (1988) argue that three waves or shifts in energy analysis have occurred. The first wave, from the 1940s to the early 1970s, was dominated by economists emphasizing the importance of energy to the economic performance of societies. Studies frequently measured economic performance and growth – especially things like Gross National Product – and compared these to the amount of energy a given country consumed. Such assessments found strong parallelism between energy use and economic growth, and perpetuated the uncontested idea that increases in energy consumption were essential to the continued growth of the American economy. Energy policy, then, consisted of assessing economic performance and energy consumption (compiling sales data and measurements of consumption), and devising strategies to ensure adequate supply to guarantee economic growth.

The second wave began when contemporary thinking about energy was shattered by the energy crises of the 1970s. This "second wave" challenged the relationship between energy and economic well-being. New studies suggested that advanced societies greatly differed in their energy consumption; cross-national surveys, longitudinal analyses, and examinations of energy use patterns across countries with similar standards of living all seemed to point in the same direction: a threshold level of high energy consumption had to be met for a society to achieve industrialization, but after that threshold had been crossed a wide latitude in the amount of energy needed to sustain standards of living existed. Energy analysis became a means of finding out how much efficiency could be achieved and exploring alternatives for those countries that had already crossed the consumption threshold.

The "third wave," while it was certainly gaining momentum earlier, started to take hold near the end of the 1970s and continues into today. This wave of studies was predominately concerned with undertaking scenarios and forecasts of the future. Energy policy analysis tended to debate different technological options, and provided insight into how supply and demand should be managed to create a more sustainable society. Analysis frequently extrapolated current trends, created a picture of a future world, and gave policymakers different options for accomplishing such a vision.

Naturally, the tendency for energy myths to continue unrecognized makes predicting energy futures especially challenging. In some ways, this is what draws many analysts to it. Philip J. Brown (1984) comments that after the energy crises of the 1970s, one of the reasons everyone wanted to undertake energy forecasts was that they recognized the importance of energy to everyone's lives. But Brown suggests they also recognized the sheer statistical challenge and utter complexity of undertaking long-range energy forecasts. Brown notes that even the best analysts have difficultly forecasting same-day political elections. Forecasting an election requires the synthesis of a vast amount of information, where (a) votes are recorded in a single district; (b) the response of the election is one-dimensional (i.e., one winner and one or many losers); (c) a full set of data is available for verification and recounting; and (d) voting takes place primarily at one point in time (election day). Energy forecasts, in contrast, are much more complicated: data often spans numerous locations and institutions; the response is multi-dimensional, depending on the information one is seeking; a full set of data is often not available or verifiable; and data collection typically takes place over many months. And, given the relative simplicity of election forecasting, consider how many analysts still make mistakes.

The experts are not alone in getting things wrong. In their assessment of household energy consumption, Loren Lutzenhiser and Bruce Hackett (1993) note that because energy is intangible, most people quantify their consumption in non-technical terms, such as average cost. Consumers also misestimate energy associated with lights, refrigerators, heating and cooling requirements. When investing in energy technologies, ordinary people often require unrealistically quick payback times. At the same time, Americans have built their lifestyles around artificially cheap energy – so they consume it impulsively.

The way both experts and consumers think about energy is further compounded by unknown surprises. In their analysis of European energy forecasts, the International Centre for Integrative Studies (2000, p. 8) classified at least three types of surprises that tended to greatly skew scenarios: improbable surprises (such as war in the Balkans); imaginable surprises (such as oil price shocks); and natural surprises (e.g., earthquakes and other natural disasters).

But energy forecasts recurrently do more than just predict the future – they can inadvertently shape it. William McDowall and Malcolm Eames (2006) argue that energy scenarios often mix descriptive and normative examination, but are able to package their thinking as conclusive analysis (rather than recognizing some of their value based assessments). McDowall and Eames note that theorists working on hydrogen futures often couple formal quantitative extrapolations with visions that elaborate a desirable future. Thus, by pointing to drivers of technological change, they make their desired future seem inevitable – and so increase the likelihood that such a future becomes possible.

Sociologists and political scientists have tended to refer to such events as "self-fulfilling prophecies." Theorist Robert W. Cox (1992, p. 133) notes that some of the most prolific ideas in contemporary society – that of the "economy" or "national sovereignty" – exist only because they are constantly reproduced in people's minds. He summed it up eloquently by remarking that "the state has no physical existence, like a building or a lamp-post; but it is nevertheless a real entity. It is a real entity because everyone acts as though it were." Moreover, once ideas become entrenched, they become difficult to dislodge. Economist John Kenneth Galbraith (2006, p. 86) mused that "economists are economical, among other things, of ideas; most make those of their graduate days last a lifetime."

K. Matthias Weber (2004) adds that most foresights and predictions involving energy appear as analytical exercises, but nonetheless have secondary – generally surreptitious – roles in shaping research agendas and technological choices. Such analysis typically works from basic assumptions that support the existing system and reinforce particular socio-technical arrangements. Weber concludes that the foresight processes focus only on selective issues, tend to underestimate uncertainties and contingencies, ignore the need for social adaptivity, and often overestimate their own influence.

As an historical example, consider the widespread view of nuclear power in the 1940s and 1950s. While not nearly as uniform and comprehensive as the "third wave" of energy forecasts undertaken near the end of the 1970s, Robert M. Hutchins, the president of the University of Chicago, stated in 1946 that nuclear power would make "heat so plentiful that it will even be used to melt snow as it falls." Hutchins went on to suggest that

> a very few individuals working a few hours a day at very easy tasks in the central atomic power plant will provide all the heat, light, and power required by the community and these utilities will be so cheap that their cost can hardly be reckoned.
> (Ford and Daniel, 1986, p. 30)

Lewis Strauss (1954, p. A1), the chairperson of the Atomic Energy Commission (AEC), remarked that atomic power would usher in an age where:

> It is not too much to expect that our children will enjoy in their homes electrical energy too cheap to meter, will know of great periodic regional famines in the world only as matters of history, will travel effortlessly over the seas and under them and through the air with a minimum of danger and at great speeds, and will experience a lifespan far longer than ours as disease yields and man comes to understand what causes him to age.

Yet history would show that such predictions fell prey to three of Weber's fallacies: underestimation of uncertainties (policymakers are still striving to improve nuclear waste management and reactor safety), a disregard of the need for social adaptation (most people still hold negative views of nuclear power stemming from Three Mile Island and Chernobyl); and an overestimation of the influence of the government and AEC (no new nuclear reactors have been ordered in the United States since 1978) (Sovacool, 2005). Contrary to the optimistic expectations of the 1950s, debate over nuclear power became so bitter in the 1970s and 1980s that David J. Rose (1981, p. 80) characterized it as "proceeding with the intelligence, grace, and charity of a duel in the dark with chain saws."

15.3. EXCAVATING AMERICAN ENERGY MYTHOLOGY

In the hopes of challenging traditional thinking about energy policy, the 13 myths explicated in this text illustrate the broad sweep of misinformation and presuppositions that underpin everyday decisions about energy. One lesson from examining these myths is that educated people can have opposing views. Take the issue of public intervention versus free-market solutions. Jerry Taylor and Peter Van Doren argue that energy prices are reasonable reflections of market conditions, and that any price distortions that do exist are principally the result of current government policy. The best remedy for such pricing problems, the thinking goes, is to eliminate distorting policies. Similarly, Amory Lovins describes the lavish subsidies and regulatory shortcuts given to favored technologies that cannot compete unaided. He recommends that a "subsidy-free zone" be created to correct the distortions introduced by "misguided federal policies." The single biggest way the government can help, according to Lovins, is to get out of the way.

In contrast, several chapters call for sizeable increases in federal involvement in the creation of energy technology solutions. Joe Romm, for instance, contends that all alternative fuel vehicle pathways require technology advances and strong government action to succeed. Daniel Kammen and Greg Nemit call for a 5- to 10-fold increase in federal support for energy R&D. Benjamin Sovacool, Richard Hirsh, and Marilyn Brown all call for greater federal support for the development of next-generation energy technologies. Taking a more moderate view, Rodney Sobin argues more strongly in favor of market-pull policies instead of technology push strategies.

Consonantly, the myth that the energy crisis is "hype" inhibits mobilizing the sizeable resources needed to deliver energy technology solutions. Greater public knowledge is one way to ensure that critical energy issues are understood. But even authors in this text dissent as to how this should be accomplished. Rosalyn McKeown focuses on the need to raise public awareness through environmental education and free choice learning opportunities. Dan Kammen and Greg Nemet, in contrast, emphasize the need for investment in science education and R&D to keep the technology pipeline full. A variant on this theme is Benjamin Sovacool and Richard Hirsh's recommendation that an expanded R&D effort needs to be both efficient (e.g., by eliminating duplication of effort across states through common federal legislation) and effective (by targeting the most important barriers, which may be social, economic, cultural, or technical).

Other disagreements impact each of the dimensions of the energy sustainability indicator (ESI) mentioned in the introductory chapter: oil security, electricity reliability, energy efficiency, and environmental quality. Such differences of opinion need to be fully debated.

In addressing the issue of ***oil security***, Jerry Taylor and Peter Van Doren question the view that conventional crude oil is becoming scarce; they also point to the sizeable deposits of unconventional oil deposits found in North American tar sands and shale oil. To address oil price volatility, long-term futures contracts are their preferred market mechanism. On the other hand, the chapters by Joe Romm, Lee Lynd *et al.*, and Marilyn Brown argue that improved efficiency and alternative fuels are critical. Joe Romm narrows in on energy efficiency and plug-in hybrid electric vehicles (HEVs) as the two best options for addressing oil security and greenhouse gas concerns. An efficient, plug-in HEV run on a blend using cellulosic ethanol is his favored ultimate solution. Lee Lynd and his colleagues emphasize the virtues of cellulosic ethanol as a sustainable transportation fuel, and they explain how a realistic progression of technology advances could make this practical and affordable. Marilyn Brown details the stagnant fuel economy of vehicles and the need to promulgate stricter CAFE standards.

To ensure ***electricity reliability***, Tom Casten and Robert Ayres emphasize the rewards from removing barriers to efficiency improvements and distributed generation (gas-fired and renewable). The power system's virtually frozen inefficiencies condone excessive fuel consumption and exacerbate environmental, security, and financial problems. Benjamin Sovacool and Richard Hirsh also emphasize the value of distributed generation, which includes both fossil fueled and renewable energy generators. Rodney Sobin narrows his focus on the value of renewable resources for power generation, stating that "over the long term, renewable energy can displace fossil energy to move our electrical and broader energy systems toward a sustainable path of meeting human needs."

Amory Lovins describes the myth that ***energy efficiency*** is "tapped out," which leads people to underestimate how much energy they can save. He believes that 30 years of experience has revealed that efficiency has numerous obstacles, possibly as great as 80 different sets of market failure. Lovins argues that each of these failures can be convertible to a business opportunity if the myth can be challenged. Similarly, Ed Vine, Marty Kushler, and Dan York underscore the business case for energy efficiency, challenging the view that energy efficiency cannot be relied upon as a utility system resource. Jerry Taylor and Peter Van Doren, on the other hand, present the case that demand-side management programs have proven unable to deliver significant demand reductions, that they have been costly, and that evaluations of their cost-effectiveness have been plagued by methodological flaws.

The thirteen myths uncover numerous points and counterpoints pertaining to energy and ***environmental quality***. With respect to climate change, Tom Wilbanks emphasizes the key role already being played by developing countries and spotlights their investment in adaptation strategies as part of an integrated approach to reducing climate impacts. Eileen Claussen and Janet Peace, on the other hand, emphasize domestic opportunities for immediate investment in low- and no-cost mitigation measures. Indeed, their different emphasis accentuates one of the key dilemmas concerning environmental activism: should American citizens focus on local action (i.e., reducing greenhouse gas emissions within the country) or global action (i.e., increasing foreign assistance to underdeveloped nations with rapidly growing energy demand)? Sociologists Frederick H. Buttel and Peter J. Taylor (1992) caution that efforts in the past to concentrate on global problems have paralyzed local attempts at improving the environment, and that endeavoring to fight local problems can unintentionally debilitate global efforts at fighting environmental destruction.

The fate of the 13 myths is uncertain. One worrisome possibility is that they will become self-fulfilling prophesies, much like the creation of the "state" or "sovereignty." The rewards that distributed generation can deliver may not materialize if the myth prevails that today's power system is already optimized, and if the barriers to efficiency and distributed generation are not removed. If society is unwilling to commit to investments in energy R&D needed to shrink the land requirements of cellulosic ethanol, the myth that food and fuel cannot both be accommodated will become all too real. If consumers continue to underestimate their opportunities to save energy while saving money, then these prospects will go untapped. If the hydrogen economy maintains its top-billing status as the solution to oil dependency, alternatives such as plug-in HEVs and cellulosic ethanol may never receive the focus needed to become cost-effective. The persistence of energy myths could foreclose important future energy options.

15.4. POSTULATING FOUR ENERGY MAXIMS: INCLUSIVITY, SYMMETRY, REFLEXIVITY, AND PRUDENCE

Given the tendency for myths relating to energy and American society to persist; the mounting energy challenges facing the nation; and the fact that most energy scenarios and forecasts are just that – *possible* futures – we propose a new way of thinking about energy based on four maxims:

1. **Inclusivity** – that the public must become more involved in energy decisions;
2. **Symmetry** – that proper analysis of energy technologies must focus on both social and technical issues;
3. **Reflexivity** – or that analysts must be self aware of their own assumptions; and
4. **Prudence** – that the decisions made regarding energy technologies must benefit existing and future generations.

The first postulate, *inclusivity*, recognizes that the diverse viewpoints of the public must be woven more completely into energy policy decisions. At the height of the cold war, Harvey Brooks (1984) – a professor of technology and public policy at Harvard University – asked a simple question: what should the general public do when experts disagree? At the time, a number of technical issues – smallpox vaccination, fluoridation of drinking water, atmospheric testing of nuclear weapons, the health hazards of persistent organic pollutants like dichloro-diphenyl-trichloroethane (DDT) – were left seemingly unresolved by scientific experts.

Brooks commented that policy disputes were always inherently value stricken, and that no practical way of disentangling social interests from technical issues exists. Brooks concluded that policy issues could only be resolved by mixing together experts and generalists from the public so that the values and preferences of common people were heard. Brooks suggested that this provided more equity, as experts remain specialists over their field, but generalists remain "experts" on the preferences of society. "Only continual confrontation between generalists and experts," Brooks concluded, "can synthesize the values of society and the facts of nature into a policy decision that is both politically legitimate and consistent with the current state of technical knowledge" (p. 40). Philip J. Frankenfeld (1992) adds that many of the hazards in modern society – dangerous chemicals and wastes, nuclear power, genetically engineered organisms – demand that the public become more active in policymaking. Frankenfeld proposed creating a polity where each technological citizen is given four rights: the right to knowledge and information, the right to participation, the right to guarantees of informed consent, and the right to life or limitation from danger. Or, as Congressperson Mark Udall (2005) put it, "inclusion breeds participation."

To study some aspect of energy technologies, most people simply have to walk outside or look around their home. The public must become more active participants so that the energy technology preferences selected for integration into society better match their interests. People should be encouraged to participate in public discussions, seminars, and debates on energy policy so that their views are considered in the development of energy policies. And the government should promote educational and informational programs on energy for local populations, through the medium of schools as well as a range of free-choice learning opportunities.

Our second postulate is one of *symmetry*: that is, policy analysis of energy technologies should focus simultaneously on social and technical issues, rather than just one or the other. Focusing on the symmetrical dimensions of technological development has at least two implications for understanding the evolution of energy technologies. For one, it reminds us that the current energy system – with its gas stations, oil refineries, electric substations, transmission lines, expansive natural gas pipelines, coal mines, and varying types of generating and consuming technology – was and is by no means inevitable. Instead, each of these technologies is the product of social negotiation and compromise. Since the current system was *chosen* and elaborated upon by actors, it can also be changed by human participants as well. Additionally, making visible the contingency of the energy technologies allows us to study and analyze the factors that make current technologies socially acceptable. In other words, symmetrical analysis helps show us what social conditions are necessary for a given technology (or set of technologies) to succeed, at the same time such conditions may make other technologies unacceptable.

Traditionally, technologists and policymakers often attempted to describe technological development of energy systems by sharply demarcating the "technical" from the "social." Sociologist John Law (In Schot, 1992, p. 38) comments that such descriptions often supplemented technical discussions with a list of the "social" factors that influenced development, as if "one is presented with a balance sheet with society (or the economy, or science, or politics) on the one hand and technology on the other. Analysis becomes the study of transfers between columns."

In contrast, we urge a symmetrical approach that looks at the social and technical aspects of energy technologies. After all, when novelist Upton Sinclair (1927, p. ix) observed his fellow Californians react to the oil boom of the 1920s, he decided to write a novel called *Oil*! "Don't you see what we've got here?" Sinclair remarked to his wife. "Human nature laid bare!" Eugene A. Rosa et al. (1988, p. 149) suggest that:

> Energy, though fundamentally a physical variable, penetrates significantly into almost all facets of the social world. Life-styles, broad patterns of communication and interaction, collective activities, and key features of social structure and change are conditioned by the availability of energy, the technical means for converting energy into usable forms, and the ways energy is ultimately used.

And Lynton K. Caldwell (1976, p. 32) noted the intrinsically social nature of BQion, processing, and use by remarking that "if there is a comprehensive energy problem, it is a problem of choice and value in a world of finite capabilities. It is therefore also a moral and political problem, and for this reason will not yield to a purely technical solution."

Thus, we believe an understanding of politics, economics, sociology, psychology, and history is elemental in ensuring that policymakers comprehend the depth and range of their actions concerning energy. In his introduction to the history of the U.S. Department of Energy, Jack M. Holl (1982) suggests that "successful change, innovation, or reform requires an understanding of historical forces which have contributed to the making of the present. Like a person with amnesia, an institution without memory lacks purpose, direction, and identity" (pp. 10–11).

Applying a symmetrical analysis in this way helps reveal the contingency of technological development. As David Nye (1999, p. 3) comments, "large-scale systems, such as the electric grid, do have some flexibility when being defined in their initial phases; however, as ownership, control, and technical specifications are established, they become more rigid and less responsive to social pressures." In other words, Nye suggests that successful energy technologies often appear predictable only after they become widely used. In this way, the notion of symmetry emphasizes that the question of whether a technology works – or is "shelved" or "marginalized" – cannot be answered definitively prior to its adoption. The question must remain open-ended; only when such technologies become fully integrated into society can such a question be answered, and even then its future success will remain an open question.

Our third postulate is one of *reflexivity*: analysts and policymakers must become more self-aware of their own hidden values. This postulate derives largely from sociologist David Bloor, who argued that scholastic inquiry must be, at least in part, reflexive. As Bloor (1976, p. 5) clarified:

> [Sociology should] be reflexive. In principle its patterns of explanation would have to be applicable to sociology itself...It is an obvious requirement of principle because otherwise sociology would be a standing refutation of its own theories.

Bloor believed that recent trends in the sociology of science have yielded interesting insights into the transmission of knowledge, but failed to critically examine a number of their own assumptions.

Reflexivity involves not just being critical of opposing views, but also engendering skepticism concerning one's own knowledge. Sociologist Steve Woolgar (1988) refers to this as "benign introspection," or reflexivity characterized as self awareness. Sociologist Malcolm Ashmore (1989) accredits it simply as "thinking more deeply about what we do." Michael Lynch (2000) adds that reflexivity can include training oneself methodologically to recognize the philosophical roots and historical context of their views, becoming more self conscious of personal biases, and learning to critically reflect on one's own personal values.

Promoting reflexivity also implicitly recognizes that all knowledge is situated, or built on a foundation of implicit doctrines and ideas. Mats Alvesson and Kai Sköldberg (2000, p. vii) note that reflexivity encompasses "above all a question of recognizing fully the notoriously ambivalent relation of a research's text to the realities studied." Over time, the values and interests of a given person, institution, or culture can naturalize practices to the point where they become taken for granted. Sociologists Daryl Chubin and Sal Restiva (1983, p. 69) went so far as to claim that:

> Orthodox historians, philosophers, psychologists, and sociologists of science tend to want science to stand still and remain in good health while they study it. But while they are studying science – usually after idealizing it, in part by purifying it of its social trappings – the science is changing. They marvel at its "success" without considering the contribution of pragmatic criteria, "tinkering," and "trial-and-error" to the "success" of "pure" science. Finally they act as apologists and ideologues of science.

The challenge, Chubin and Restiva conclude, is to become more critical and self-aware of one's own epistemic presumptions instead of tacitly or imperceptively accepting them.

Currently, most consumers remain patently *un-reflexive* regarding their energy decisions. Chapters in this book, for instance, have revealed that some Americans believe the electricity entering their home is derived from "the plug-in-the-wall" rather than a power plant; a majority of those Americans recognizing that electricity comes from power stations insist that it is generated mostly at hydroelectric and nuclear facilities (instead of, correctly, coal plants); and that, for the most part, people tend to overestimate their own knowledge concerning energy and society, if indeed they contemplate such issues in the first place. One recent study even found that nearly 70 percent of flex-fuel vehicle owners were unaware that they were driving an automobile that could run on alternative fuels (Hess, 2006, p. 54). Thus, the need for energy analysts, policymakers, and the public to become more reflexive is vigorously vital. The double invisibility of energy myths – the fact that many energy technologies have become naturalized in society, and that myths about them add a further layer of distortion – further heightens the importance of reflexivity as a postulate.

The final – and perhaps most important postulate – is one of energy *prudence*. A truly prudent energy strategy is encapsulated in the following statement from Douglas Maclean (1980, p. 3):

> None of the problems we confront in forming an energy policy is more important or more basic than finding a satisfactory balance between securing the resources to meet our own current needs and conserving and protecting these resources and the environment for the use of generations that will succeed us.

This is consistent with the original definition of sustainability as set forth in *Our Common Future* (1987), the report of the World Commission on Environment and Development, also known as the Brundtland Report. According to this report, sustainable development "meets the needs of the present without compromising the ability of future generations to meet their own needs."

Our own notion of energy *prudence* draws largely from the concept of "appropriate technology" and the fields of industrial ecology, environmental impact assessment and political geography. The definition of "appropriate technology" shares much with Lewis Mumford's (1964) notion of democratic technology, which he referred to as person-centered, resourceful, and durable. Democratic technologies, for Mumford, typically draw upon small-scale methods of production, local ownership and control, and an element of synergy with the natural environment (Pursell, 1993).

In his widely acclaimed *Small is Beautiful: Economics as if People Mattered*, economist E.F. Schumacher (1973) argues that large, expensive technological projects continue to fail (or bring about unintended or undesirable consequences) because they are being implemented on the wrong scale. Schumacher developed the term "intermediate technology" – later called "appropriate technology" – to encompass his belief that technologies must: (a) support local economic growth within a given community; (b) create independence from outside sources of knowledge and capital; (c) employ the simplest production methods available; and (d) use local materials that minimize harm to the social and natural environment (pp. 162–168).

Comparably, practitioners in the field of environmental impact assessment have abandoned their classic approach of narrowly analyzing the "environmental" impacts of technologies in favor of a more holistic methodology assessing the way technologies influence a panoply of social, economic, cultural, and ecological forces (Shopley and Fuggle, 1985; Erickson, 1994; Giplin, 1995). What was once a field solely examining, say, the effects of a large dam on local salmon populations would now investigate that dam's influence on property rights, the expansion of local agriculture, community employment, tax structure, disturbance of viewscape, educational potential, and a whole host of "sustainability concerns" (Pope et al., 1994; Gismondi, 1997; Payraudeau and ven der Werf, 2005).

Practicing energy prudence requires a holistic way of thinking about sustainability. Political geographers Martin Mowforth and Ian Munt (2003) have argued that most rhetoric concerning "sustainable energy" or "sustainable development" focuses too narrowly on just "energy," the "environment," or the "economy." Instead, Mowforth and Munt insist that technological decisions must be based according to their collective environmental, social, cultural, economic, and educational consequences.

The future must be open to small-scale, localized energy systems as well as centralized, large-scale systems. Just as the technology options are diverse, so are the criteria for selection. Specifically, analysts should consider the following types of questions:

1. Does it harm the environment?
2. Does it degrade the social structure of local communities?
3. Does it damage traditional culture?
4. Does it benefit local economies and utilize local resources?
5. Does it provide education or local participation?
6. Does it promote efforts aimed at conservation and efficiency?
7. Does it foster the well being of future generations?

While such inquiries may sound blatantly obvious, most assessments of technology continue to ignore the *entire* range of possible impacts a given energy system can have on society. Furthermore, some technological decisions promote some forms of sustainability while directly harming others. For instance, the deployment of a large, nuclear plant in a small, rural community could greatly benefit the local economy, but could also distort the social structure of the community by inflating local prices and increasing outside ownership of community assets. Similarly, building a large dam may help displace a polluting coal plant (thus improving the environment), but in the process destroy aquatic habitats and force the massive relocation of homes and businesses.

The point is that truly *prudent* energy decisions must fully take into account the complete array of potential socio-technical consequences. In the end, achieving prudence will point to energy choices that borrow from nature (by using renewable resources or energy efficiency practices) rather than those that borrow from the future (by depleting nature's resources or locking in polluting options). We must never forget that the measure of a given culture is not necessarily the tools it can develop, but instead the use it makes of them.

15.5. FINAL REFLECTIONS

Overall, this book has strived to educate and inform readers about energy policy by unearthing key myths that persevere in American culture and underpin everyday energy decisions. Exploring myths pushes otherwise cloaked cultural dimensions to the foreground and reminds us that energy technology has both social and technical facets. In this very particular sense, myths do not refer to the absolute authenticity of a given fact, but instead represent what people perceive to be true. Such perceptions and beliefs about energy and society represent powerful forces that can both motivate and restrict change.

Engaging authors from diverse backgrounds (universities, think tanks, industry, and government) in a dialogue about energy technology and policy was destined to promote differences of opinion. One lesson from examining these myths is that educated people can have opposing and contradictory views. Much like the tale of the turtle and the fish, dissimilar experiences, interests, and values can produce inherently clashing attitudes concerning energy policy and technology.

Another is that the technological options available to American society are indeed assorted and multifarious. Utilities can rely on pulverized coal plants, decentralized solar panels, combined cycle natural gas plants, concentrated wind farms, large hydroelectric facilities, or energy efficiency practices – naming just a few – to meet growing electricity demand. Politicians can employ renewable portfolio standards, system benefits funds, production tax credits, subsidies, programs, and legislation to promote different energy technologies. Correspondingly, people can purchase vehicles powered by any of a number of fuels – gasoline, diesel, bio-diesel, electricity, cellulosic ethanol, or hydrogen – relying on the current refueling infrastructure or requiring a transformed system.

A third lesson is that these different technologies have produced distinct ways of conceptualizing energy. The clash between nuclear, fossil, and renewable resources; supply-side and demand-side measures; hydrogen vehicles and plug-in-hybrids;

government intervention and the marketplace is something more than a conflict over technology. It represents a battle about new technologies versus entrenched interests; a contest over how best to manage power systems, industrial utilities, and the energy use of businesses and firms; and a conflict over competing conceptions of modern life and identity. Moreover, the struggle is also about the immaterial and epistemic concepts of centralization versus decentralization, consolidated versus dispersed control over natural and human resources, conducting business as usual contrasted with considering a more complete set of environmental, security, reliability, and public health externalities. The struggle over energy policy is at once material and immaterial, institutional as well as technological, social as well as scientific.

But a distinct, final lesson is that our energy fate is inherently uncertain and open-ended: many technology and policy options are available, and no silver bullet exists. The mounting energy challenges demand the pursuit of multiple energy pathways; but at the same time, limited policy levers and investment capital prevent all possibilities from being pursued. Whether we endeavor to create an energy future on the basis of distorted, mythic representations or critical, reflexive and prudent strategies is ours alone to decide.

REFERENCES

Alvesson, Mats and Sköldberg, Kaj: 2000, *Reflexive Methodology: New Vistas for Qualitative Research*, Sage, London, UK.

Ashmore, Malcolm: 1989, *The Reflexive Thesis: Wrighting Sociology of Scientific Knowledge*, University of Chicago Press, Chicago, IL, USA.

Bloor, David: 1976, *Knowledge and Social Imagery*, University of Chicago Press, Chicago, USA.

Brooks, Harvey: 1984, "The Resolution of Technically Intensive Public Policy Disputes." *Science, Technology, & Human Values* 9(1), Winter, pp. 39–50.

Brown, Philip J.: 1984, "Forecasts and Public Policy," *The Statistician* 33(1), pp. 51–63.

Brundtland, Gro Harlem: 1987, *Our Common Future*, World Commission on Environment and Development, Oxford University Press, Oxford.

Buttel, Frederick H. and Taylor, Peter J.: 1992, "Environmental Sociology and Global Environmental Change: A Critical Assessment," *Society and Natural Resources* 5, pp. 211–230.

Caldwell, Lynton K.: 1976, "Energy and the Structure of Social Institutions." *Human Ecology* 4(1), pp. 31–45.

Chubin, Daryl E. and Sal, Restivo: 1983, The 'Mooting' of Science Studies: Research Programmes and Science Policy," in Karin D. Knorr-Cetina and Michael Mulkay (eds), *Science Observed: Perspectives on the Social Study of Science*, Sage, London, UK, pp. 53–84.

Cox, Robert W.: 1992, "Towards a Post-Hegemonic Conceptualization of World Order: Reflections on the Relevancy of Ibn Khaldun," in James N. Rosenau and Ernst-Otto Czempiel (eds), *Governance Without Government: Order and Change in World Politics*, Cambridge University Press, New York, USA, pp. 133–152.

Durkheim, Emile and Mauss, Marcel: 1963, *One Some Primitive Forms of Classification: Contribution to the Study of Collective Representations*, University of Chicago, Chicago, USA.

Erickson, Paul A.: 1994. *A Practical Guide to Environmental Impact Assessment*, University of California Press, San Diego, USA.

Fleck, Ludwig: 1979, *Genesis and Development of a Scientific Fact*, University of Chicago, Chicago, USA.

Ford, Daniel: 1986, *Meltdown: The Secret Papers of the Atomic Energy Commission*, Simon & Shuster, New York, USA.

Frankenfeld, Phillip J.: 1992, "Technological Citizenship: A Normative Framework for Risk Studies," *Science, Technology, and Human Values* 17(4), pp. 459–484.

Galbriath, John Kenneth: 2006, "Obituary: John Kenneth Galbraith," *The Economist*, 379(8476), p. 86.

Giplin, A.: 1995. *Environmental Impact Assessment: Cutting Edge for the Twenty-First Century*, Cambridge University Press, Cambridge.

Gismondi, Michael: 1997, "Sociology and Environmental Impact Assessment," *Canadian Journal of Sociology* 22(4), pp. 457–449.

Hess, Glenn: 2006, "Bush Promotes Alternative Fuel," *Chemical and Engineering News*, pp. 50–54.

Holl, Jack M.: 1982, *The United States Department of Energy: A History*, DOE, Washington, DC, USA.

International Centre for Integrative Studies: 2000, *Cloudy Crystal Balls: An Assessment of Recent European and Global Scenario Studies and Models*, European Environmental Agency, Paris, France.

Kuhn, Thomas S.: 1962, *The Structure of Scientific Revolutions*, University of Chicago, IL, USA.

Kuhn, Thomas S.: 1977, *The Essential Tension: Selected Studies in Scientific Tradition and Change*, University of Chicago, IL, USA.

Ling, L.H.M.: 2002, "The Fish and the Turtle: Multiple Worlds as Method," in Michael Brecher and Frank P. Harvey (eds), *Millennial Reflections on International Studies*, University of Michigan Press, Ann Arbor. MI, USA, pp. 283–313.

Lutzenhiser, Loren and Hackett, Bruce: 1993, "Social Stratification and Environmental Degradation: Understanding Household Carbon Dioxide Production," *Social Problems* 40(1), pp. 50–73.

Lynch, Michael: 2000, "Against Reflexivity as an Academic Virtue and Source of Privileged Knowledge," *Theory, Culture & Society* 17(3), pp. 363–375.

Maclean, Douglas: 1980, "Benefit-Cost Analysis, Future Generations and Energy Policy: A Survey of the Moral Issues," *Science, Technology, & Human Values* 5(31), pp. 3–10.

McDowall, William and Eames, Malcolm: 2006, "Forecasts, Scenarios, Visions, Backcasts and Roadmaps to the Hydrogen Economy: A Review of the Hydrogen Futures Literature," *Energy Policy* 34, pp. 1236–1250.

Mowforth, Martin and Munt, Ian: 2003, *Tourism & Sustainability: Development and New Tourism in the Third World*, Routledge, London, UK.

Mumford, Lewis: 1964, "Authoritarian and Democratic Technics," *Technology and Culture* 5, pp. 2–12.

Nye, David: 1999, *Consuming Power: A Social History of American Energies*, MIT Press, New York, NY, USA.

Payraudeau, Sylvain and ven der Werf, Hay: 2005, "Environmental Impact Assessment for a Farming Region: A Review of Methods," *Agriculture, Ecosystems and Environment* 107, pp. 1–19.

Pickering, Andrew: 1993, "The Mangle of Practice: Agency and Emergence in the Sociology of Science," *American Journal of Sociology* 99(3), pp. 540–598.

Pope, Jenny, Annandale, David, and Morrison-Saunders, Angus: 2004, "Conceptualizing Sustainability Assessment," *Environmental Impact Assessment Review* 24, pp. 595–616.

Price, Derek de Sola: 1966,"Collaboration in an Invisible College," *American Psychologist* 21, pp. 1011–1018.

Pursell, Carroll: 1993, "The Rise and Fall of the Appropriate Technology Movement in the United States, 1965–1985," *Technology & Culture* 34(3), pp. 629–637.

Rosa, Eugene A., Machlis, Gary E., and Keating, Kenneth M.: 1988, "Energy and Society." *Annual Review of Sociology* 14, pp. 149–172.

Rose, David J.: 1981, "Energy and History," *American Heritage* 32 (June/July), pp. 79–80.

Schot, Johan W.: 1992, "Constructive Technology Assessment and Technology Dynamics: The Case of Clean Technologies," *Science, Technology, and Human Values* 17(1), pp. 35–36.

Schumacher, E.F.: 1973, *Small is Beautiful: Economics as if People Mattered*, Harper & Row, New York, NY, USA.

Shopley, J.B. and Fuggle, R.F.B.: 1985, "A Comprehensive Review of Current Environmental Impact Assessment Methods and Techniques," *Journal of Environmental Management* 18, pp. 25–47.

Sinclair, Upton: 1927, *Oil! (California Fiction)*, University of California Press, Los Angeles, CA, USA.

Sovacool, Benjamin K.: 2005, "Think Again: Nuclear Power," *Foreign Policy* 150 (September/October), [online] www.foreignpolicy.com/story/cms.php?story_id=3250, accessed July 2006.

Strauss, Lewis: 1954, “Speech to the National Association of Science Writers, September 16th, 1954,”*New York Times* (September 17), p. 1A.

Udall, Mark: 2005, *Presentation at the Alliance to Save Energy*, Washington, DC, July 15, p. 1.

Weber, K. Mattias: 2004, “Expectations, Foresight and Policy Portfolios: Shaping of or Adapting to the Future?” Presentation at the Expectations in Science and Technology Research Workshop, Risoe National Laboratory, Denmark, April 29–30, 2004, [online] http://www.york.ac.uk/org/satsu/expectations/Roskilde%202004/Weber%20Foresight, %20portfolios%20and%20expectations.ppt, accessed July 2006.

Woolgar, Steve: 1988, “Reflexivity is the Ethnographer of the Text,” in S. Woolgar (ed.) *Knowledge and Reflexivity: New Frontiers in the Sociology of Scientific Knowledge*, Sage, London, UK, pp. 1–13.

ACRONYMS

ACEEE	American Council for an Energy Efficient Economy
AEO	Annual Energy Outlook
AER	Annual Energy Review
ASE	Alliance to Save Energy
Btu	British thermal unit
CAFE	corporate average fuel economy
C	carbon
CHP	combined heat and power
CO_2	carbon dioxide
DG	distributed generation
DOE	U.S. Department of Energy
EEI	Edison Electric Institute
EERS	energy efficiency resource standards
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act
EPRI	Electric Power Research Institute
ESCOS	energy service companies
ESI	energy sustainability indicator
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
GDP	gross domestic product
GHG	greenhouse gas
GW	gigawatt
HEV	hybrid electric vehicle
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IPMVP	International Performance Measurement and Verification Protocol
kWh	kilowatt-hour
LBL	Lawrence Berkeley National Laboratory
LCOE	levelized cost of electricity
MBtu	million Btu
mmbd	million barrels of oil per day
MtC	million metric tons of carbon
MW	megawatt
mpg	miles per gallon
NCEP	National Commission on Energy Policy
NEETF	National Environmental Education and Training Foundation

NO_x	nitrogen oxides
NREL	National Renewable Energy Laboratory
OPEC	Organization of Petroleum Exporting Countries
ORNL	Oak Ridge National Laboratory
PBFs	public benefit funds
PM	particulate matter
ppm	parts per million
PTC	production tax credit
PURPA	Public Utility Regulatory Policy Act of 1978
PV	photovoltaic
Quad	quadrillion Btu (10^15 Btu)
R&D	research and development
RMI	Rocky Mountain Institute
RPS	renewable portfolio standard
SBCs	system benefits funds
SO_2	sulfur dioxide
SUV	sports utility vehicle
T&D	transmission and distribution
TBtu	trillion Btu
TWh	terra watt-hour
VMT	vehicle miles traveled
WADE	World Alliance for Decentralized Energy

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