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Nuclear Energy Development in Asia

Problems and Prospects

Edited by

Xu Yi-chong

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Edited by

Xu Yi-chong
Research Professor, Centre for Governance and Public Policy, Griffith University, Australia

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Preface

Over 80 per cent of the world's energy supply is currently derived from fossil sources and the energy sector accounts for 84 per cent of global CO_2 emissions and 64 per cent of the world's greenhouse gas emissions. The energy sector must be at the heart of a comprehensive programme of robust, collective actions not simply to reduce emissions at the margins, but to undertake fundamental changes in our approach to producing and consuming energy. Energy is an essential foundation for economic and personal well-being. Somehow the energy needs of the world's ever growing population must be met, and it is not an option to respond to the depleting energy resources and the climate change threat by expecting that people in many developing countries would be happy to live in the dark or would be willing to keep their energy consumption much below the level of those in rich countries.

As the world's appetite for modern energy is growing exponentially, so is the interest in nuclear power. This is driven by many factors, including rising and volatile fossil fuel prices, the geographic concentration of the remaining significant oil and gas reserves with resultant energy security concerns, and already felt climate change consequences. Some Asian countries are clearly in the lead in nuclear energy expansion – China, India and South Korea are on the top of the list. Nuclear energy expansion, however, raises a series of concerns: how can the nuclear energy industry expand without incurring any serious proliferation problems? Nuclear development requires many components of the necessary infrastructure, including legal and regulatory capability, educated and trained manpower, a stable electrical grid, access to financial and industrial resources, and the nurturing of an appropriate safety culture in the generating entity.

It has been a great challenge for me working with the contributors who are from various disciplines and I am sure it has been a great challenge too for the contributors, especially those in nuclear and electrical engineering, trying to write policy analyses. Fortunately, we have all benefited immensely from the workshop held in Brisbane in July 2009 and especially from the comments made by the workshop participants who are fine political scientists and country specialists. We thank Malcolm Cook and Michael Wesley (Lowy Institute), Ciaran O'Faircheallaigh and Leong Liew (Griffith University), Bruce Jacobs (Monash University), David Hundt (Deakin University), Andrew MacIntyre (Australian National University) and R.A.W. Rhodes (University of Tasmania).

We also thank Keith Whittam for editing the manuscript, Natasha Vary for organising the workshop, and Paula Cowan for editing and doing the index for the manuscript. We acknowledge the financial support of the

Australian Research Council and the Centre for Governance and Public Policy at Griffith University to fund the workshop.

Finally, I wish to acknowledge my special appreciation to Pat Weller, as a director of the Griffith Centre for Governance and Public Policy, and as a colleague who encouraged and supported this project from the very beginning.

Xu Yi-chong

Series Editor Preface

Concerns about the potential environmental, social and economic impacts of climate change have led to a major international debate over what could and should be done to reduce emissions of greenhouse gases, which are claimed to be the main cause. There is still a scientific debate over the likely scale of climate change, and the complex interactions between human activities and climate systems, but, in the words of no less than the Governor of California, Arnold Schwarzenegger, 'I say the debate is over. We know the science, we see the threat, and the time for action is now.'

Whatever we now do, there will have to be a lot of social and economic adapation to climate change – preparing for increased flooding and other climate-related problems. However, the more fundamental response is to try to reduce or avoid the human activities that are seen as causing climate change. That means, primarily, trying to reduce or eliminate emission of greenhouse gases from the combustion of fossil fuels in vehicles and power stations. Given that around 80 per cent of the energy used in the world at present comes from these sources, this will be a major technological, economic and political undertaking. It will involve reducing demand for energy (via lifestyle choice changes), producing and using whatever energy we still need more efficiently (getting more from less), and supplying the reduced amount of energy from non-fossil sources (basically switching over to renewables and/or nuclear power).

Each of these options opens up a range of social, economic and environmental issues. Industrial society and modern consumer cultures have been based on the ever-expanding use of fossil fuels, so the changes required will inevitably be challenging. Perhaps equally inevitable are disagreements and conflicts over the merits and demerits of the various options and in relation to strategies and policies for pursuing them. These conflicts and associated debates sometimes concern technical issues, but there are usually also underlying political and ideological commitments and agendas which shape, or at least colour, the ostensibly technical debates. In particular, at times, technical assertions can be used to buttress specific policy frameworks in ways which subsequently prove to be flawed.

The aim of this series is to provide texts which lay out the technical, environmental and political issues relating to the various proposed policies for responding to climate change. The focus is not primarily on the science of climate change, or on the technological detail, although there will be accounts of the state of the art, to aid assessment of the viability of the various options. However, the main focus is the policy conflicts over which strategy to pursue. The series adopts a critical approach and attempts to identify flaws in emerging policies, propositions and assertions. In particular, it seeks to illuminate counter-intuitive assessments, conclusions and new perspectives. The aim is not simply to map the debates, but to explore their structure, their underlying assumptions and their limitations. Texts are incisive and authoritative sources of critical analysis and commentary, indicating clearly the divergent views that have emerged and also identifying the shortcomings of these views. However, the books do not simply provide an overview, they also offer policy prescriptions.

The present volume looks at what is arguably a key energy and climate issue – the approach being adopted in Asia, where nuclear power is being touted as a key way ahead. A previous book in this series looked in detail at the situation in China. This book widens the focus to look at Asia as a whole – covering developments and policies in China, Taiwan, Indonesia, Japan, South Korea and India, as well as in Australia, as a supplier of uranium to the region.

As with the previous book on China, a key initial point to make is that nuclear is only one option on the table. Renewable energy is also a major contender. For example, China's current target is to get 15 per cent of its energy (not just electricity) from renewables by 2020, although this is likely to be raised to 20 per cent. It is pushing ahead with both wind and solar as well as hydro and biomass. As well as having major biomass and solar resources, India is already one of the world leaders in wind power utilisation. Japan was an early technological leader in photovoltaic (PV) solar. South Korea is a global pioneer in tidal energy development with around 2.6 GW of tidal barrage and tidal current turbine capacity in place or planned, well beyond anything yet considered in Europe.

Technologically and strategically, renewables clearly have a major potential in and for the region, with the resources being very large and most of these countries now having adopted Feed-In Tariff schemes to accelerate their development. The spread of wind power technology is particularly marked. It is expanding at nearly 30 per cent per annum globally and the Global Wind Energy Council estimates that by 2013 global wind generating capacity will rise to 117 GW in Asia. The potential for energy saving is also very large, especially since, in some as yet undeveloped areas, there is an opportunity to invest in new state-of-the-art energy efficient systems on greenfield sites.

However, as in parts of Europe, despite its problems (as witness the various accidents that have befallen the reactor programme in Japan and the relatively slow progress made in India), the nuclear option is also seen as attractive. This book explains why, and looks at what is envisaged. With, until recently, progress in much of Western Europe and the USA stalled, Western purveyors of nuclear technology have long looked to the East as a potentially very large new market, but indigenous nuclear technology has emerged, including some novel ideas, like China's version of the high temperature modular 'Pebble Bed' reactor. What happens in the East may well feed back to shape what happens in the West – as well as influencing what emerges in other, less developed countries in the East.

The problems of climate change are becoming ever more apparent in this part of the world, and are likely to have more serious social and economic consequences here than elsewhere. However, at the same time, continued economic growth is seen as vital for the region, both for the developed and rapidly developing countries, with emissions continually expanding. Nuclear power is portrayed as at least part of a possible solution. As earlier books in this series have argued, there are alternative views: nuclear may prove to be an expensive and unreliable diversion from developing truly sustainable energy sources. The response from the East to the climate challenge, and the position it adopts on the nuclear issue, thus could be central not only to the future of the East, but also to the world as a whole.

Abbreviations

ADB	Asian Development Bank
AEC	Atomic Energy Commission, India
AECL	Atomic Energy of Canada Limited
AHWRs	advanced heavy water reactors
ALP	Australian Labor Party
ANSO	Australian Safeguards and Non-proliferation Office
APEC	Asia-Pacific Economic Cooperation
ATR	advanced thermal reactor
BJP	Bharatiya Janata Party, India
BNFL	British Nuclear Fuels Limited
BWR	boiling water reactor
CAEA	China Atomic Energy Agency
CEPCO	Chugoku Electric Power Co., Kansai Electric Power Co.
CGNPC	China Guangdong Nuclear Power Holding Co. Ltd
CIAE	China Institute of Atomic Energy
CNEC	China Nuclear Engineering Corporation
CNEPP	Comprehensive Nuclear Energy Promotion Plan, Korea
CNNC	China National Nuclear Power Corporation
COSTIND	Commission of Science, Technology and Industry for National Defence, China
CPI	China Power Investment Corporation
CSC	Convention on Supplementary Compensation for Nuclear Damage
CTBT	Comprehensive (Nuclear) Test Ban Treaty
DAE	Department of Atomic Energy, India
DOE	Department of Energy, USA
DPJ	Democratic Party of Japan
DPP	Democratic Progressive Party, Taiwan
EIA	Environmental Impact Assessment
FBR	fast breeder reactor
FMCT	Fissile Material Cut-Off Treaty
GHG	greenhouse gases
GNEP	Global Nuclear Energy Partnership
GWe	Gigawatt of electric
HEU	highly enriched uranium
HLW	high-level radioactive waste
HWR	heavy water reactor
IAEA	International Atomic Energy Agency
ICBC	Industrial and Commercial Bank of China

IEA	International Energy Agency
IPCC	Inter-governmental Panel on Climate Change
IUEC	International Uranium Enrichment Centre
JAEA	Japan Atomic Energy Agency
JAEC	Japan Atomic Energy Commission
JNES	Japan Nuclear Energy Safety Organisation
JNFL	Japan Nuclear Fuel Limited
KEPCO	Korean Electric Power Corporation
KHIC	Korea Heavy Industries and Construction Company
KHNP	Korea Hydro and Nuclear Power
KINS	Korea Institute of Nuclear Safety
KMT	Kumintang, Taiwan
KNFC	Korea Nuclear Fuel Company
KSNP	Korean Standard Nuclear Power Plant
kWh	kilowatt hour
LDP	Liberal Democratic Party, Japan
LEU	low-enriched uranium
LNG	liquefied natural gas
LWR	light water reactor
MDG	Millennium Development Goals
MEP	Ministry of Environmental Protection, China
METI	Ministry of Economics, Trade and Industry, Japan
MEXT	Ministry of Education, Culture, Sports, Science and Technology, Japan
MIIT	Ministry of Industry and Information Technology, China
MIT	Massachusetts Institute of Technology
MITI	Ministry of International Trade and Industry, Japan
MKE	Ministry of Knowledge Economy, South Korea
Mtoe	million tonne of oil equivalent
NDRC	National Development and Reform Commission, China
NEA	Nuclear Energy Agency
NEA	National Energy Administration, China
NEC	National Energy Commission, China
NERA	Nuclear Energy Regulatory Agency
NGO	non-governmental organisation
NISA	Nuclear and Industrial Safety Agency, Japan
NNSA	National Nuclear Safety Administration, China
NNWS	non-nuclear weapons states
NPCI	Nuclear Power Corporation of India Limited
NPPs	nuclear power plants
NPT	Nuclear Non-Proliferation Treaty
NSC	Nuclear Safety Commission of Japan
NSC	National Security Council, Korea
NSG	Nuclear Suppliers Group

NSSP	Next Steps in Strategic Partnership
NWMO	Nuclear Waste Management Organisation
NWS	nuclear weapons states
OECD	Organization for Economic Cooperation and Development
PHWR	pressurised heavy water reactor
PWR	pressurised water reactor
R&D	research and development
SASAC	State-Owned Assets Supervision and Administration Commission
SEA	Strategic Environmental Assessment
SNPTC	State Nuclear Power Technology Corporation Ltd
SOEs	state-owned enterprises
TEPCO	Tokyo Electric Power Company
TPC	Taiwan Power Company (Taipower)
UAE	United Arab Emirates
UN	United Nations
UNDP	United Nations Development Programme
WMD	weapons of mass destruction
WNA	World Nuclear Association

List of Contributors

Jeff Graham is Lecturer at the Department of International Business and Asian Studies, Griffith University, Australia. His publications include J. Graham and S. Maswood (eds), *Japan: Change and Continuity*, RoutledgeCurzon, 2002; 'Japan and the Ocean Dumping of Wastes', *Asian Studies Review*, 25(3), 2001, pp. 335–360; and 'Changing Environmental Policy Agendas: Japan's Approach to International Environmental Problems', in J. Graham and S. Maswood (eds), *Japan: Change and Continuity*, RoutledgeCurzon, 2002, pp. 125–147.

Stuart Harris is Emeritus Professor at the Department of International Relations, School of International, Political and Strategic Studies, Australian National University (ANU). Before joining ANU, Harris was the Director of the Australian Bureau of Agricultural Economics, Deputy Secretary of the Australian Department of Trade. His research interests include China's international relations, especially with the USA; regional, notably Northeast Asian, economic, political and strategic developments. His publications include 'Institutionalizing Northeast Asia: The Energy Market', in M. Timmermann and J. Tsuchiyama (eds), *Institutionalizing Northeast Asia: Regional Steps Towards Global Governance*, United Nations University Press, 2008; 'Power and Order in Northeast Asia: A Review', *Australian Journal of International Affairs*, 62(2), 2008, pp. 245–259; 'Economic Dimensions of Energy Security in the Asia-Pacific', in M. Wesley (ed.), *Energy Security in Asia*, Routledge, 2007; and 'Does China Matter: The Global Economic Issues', in Barry Buzan and Rosemary Foot (eds), *Does China Matter? A Reassessment: Essays in Memory of Gerald Segal*, Routledge, 2004. He remains active in researching and writing.

Per Högselius is Associate Professor at the Division of History of Sciences and technology, Royal Institute of Technology, Sweden. Högselius is a historian. His current research emphasis is on energy security in a historical and geopolitical perspective. He is also an active commentator in leading Swedish media on current international issues in energy policy developments. He is the author of *Östersjövägar* (*Baltic Roads)*, Atlantis, 2007); *The Dynamics of Innovation in Eastern Europe: Lessons from Estonia,* Edward Elgar Publishing, 2005; and co-author with Arne Kaijser of *När folkhemselen blev internationell: Elavregleringen i historiskt perspektiv* (*When Electricity Became and International Welfare State: Elavregleringen in Historical Perspective)*, SNS Förlag, 2007. He has also published extensively in *Energy Policy*, *Utility Policy*, and other international journals.

Lavina Lee is Lecturer at the Department of Politics and International Relations, Macquarie University, Sydney, Australia. Her research interests include the role of culture and norms in international relations, legitimacy and US hegemony, US foreign policy and developments in international law on the use of force, international security and nuclear non-proliferation issues. In 2009 Lavina was awarded a grant by Macquarie University to pursue a project on the US–India nuclear cooperation agreement and its implications for Australian nuclear policy. Her first book, *US Hegemony and Legitimacy: Norms, Power and Followership in the Wars on Iraq,* was published by Routledge in 2010.

Min Lee is Professor at the Department of Engineering and System Science, College of Nuclear Science, National Tsing Hua University, Taiwan. Professor Lee had worked at the Brookhaven National Laboratories before returning to Taiwan and joining Tsing Hua University in 1989. His research fields are probabilistic risk assessment of nuclear power plants, LWR severe accident phenomenology, heat transfer and thermal-hydraulic analyses of LWR. Professor Lee served as the Board Director of Taiwan Power Company (Taipower), a government-owned utility company, between March 2001 and September 2007. He has been a member of the Nuclear Safety Committee of Taipower since 1994, and committee member of the Management Committee of the Back End Fund of Taiwan. He is also very interested in and spends a lot of effort on the public acceptance of nuclear power and the national energy policy.

Toshihiko Nakata is Professor at the Graduate School of Engineering, Tohoku University, Aoba-Yama Sendai, Japan. His research interests include energy science, environmental impact assessment and environmental policies. His recent publications include ‘Analysis of the Market Penetration of Clean Coal Technologies and its Impacts in China’s Electricity Sector’, *Energy Policy*, 37(1), 2009, pp. 1–10; ‘Assessment of Access to Electricity and the Socio-Economic Impacts in Rural Areas of Developing Countries’, *Energy Policy*, 36(6), 2008, pp. 2016–2029; ‘Renewable Technologies for Rural Electrification in Colombia: A Multi Objective Approach’, *International Journal of Energy Sector Management*, 2(1), 2008, pp. 139–154; and ‘Design for Renewable Energy Systems with Application to Rural Areas in Japan’, *Energy Policy*, 33(2), 2005, pp. 209–219.

Sang Dongli is Associate Professor at the School of Law, Zhengzhou University, China. Sang teaches law and specialises in energy and climate change law and natural resources law. Her recent publications include 可持续发展与中国自然资源物权制度之变革，科学出版社，2006 (*Sustainable Development and System Change in China’s Natural Resources*), Sciences Publishing, 2006, and *Sustainable Development and the Innovation of Natural*

Resources Property in China and *Cases Tutorial in Environmental and Natural Resources Law* (co-edited with Shuyi Wang and Binhui Wang).

Maeng-Ho Yang is at the Korean Atomic Energy Research Institute (KAERI), South Korea. Yang has worked for the Department of Nuclear Policy Division, KAERI since 1 January 1983, and he is the Head of the Division of Nuclear Energy Policy Research and Nuclear Foreign Policy Research. His major research areas include policy research for nuclear energy development, nuclear international cooperation and R&D policy for nuclear technology development in KAERI.

Xu Yi-chong is Research Professor of Politics and Public Policy at Griffith University, Australia. Professor Xu publishes on international organisations and energy issues and is the author of *Powering China: Reforming the Electric Power Industry in China*, 2002; *Electricity Reform in China, India and Russia*, 2004; *The Governance of World Trade: International Civil Servants and the GATT/WTO,* 2004, and *Inside the World* Bank, 2009 (both with Patrick Weller); and *The Politics of Nuclear Energy in China* (2010) and is the editor of *The Politics of Sovereign Wealth Funds* (2010).

1
Nuclear Energy in Asia: An Overview

Xu Yi-chong

Nuclear power has been used as a source of energy for more than half a century and it has recently found its new significance in some developing countries. Politicians and those concerned about energy security and climate change are looking at nuclear for a solution. While in many developed countries the debate is *whether* they should phase out their nuclear energy programmes, revive them or start building new nuclear power plants (NPP), in developing countries, especially those in Asia, the issue is *how*, rather than *whether*, to build or expand their nuclear energy programmes. There is an overwhelming sense of urgency to deal with the twin challenges – energy security and climate change – which have brought about different assessments of the benefits and risks of nuclear energy. In many Asian countries, nuclear energy does not represent an imminent danger of nuclear proliferation or creating an unsolvable problem of highly radioactive nuclear wastes (Norris 1994; Frankel 1995; Dittmer 2005). Instead, nuclear energy is presented by politicians, scientists and energy specialists as an alternative source of unlimited and clean energy that would allow countries such as China or India to continue economic development with sufficient energy supplies while alleviating their energy poverty, reducing their energy security vulnerability, easing the pressure of rising energy prices and abating environmental pollution.

This new assessment of nuclear energy has led to a recent surge of activity in the nuclear field, with Asia taking the lead. Japan, South Korea and Taiwan have already developed substantial nuclear generation capacity. Nuclear power plants provide 25–35 per cent of electricity in these countries. These countries, along with other Asian countries, are now expanding their nuclear generation capacity. As of 2010, 54 power plants with a total capacity of 51 GWe were under construction worldwide and 35 of them were in Asia. China alone hosted 21 units with 21 GWe capacity, South Korea 6 units, India 5, Taiwan 2 and Japan 1. In Southeast Asia, Indonesia, Malaysia, Thailand and Vietnam are all planning to launch their nuclear energy programmes.

Is there a 'nuclear renaissance' and, if so, will it be another soon-to-evaporate fad that emerges every time energy prices rise? Or is it merely 'nuclear amnesia' because nuclear energy will never be able to meet the demand (Patterson 2006)? How is this new desire to build and expand nuclear programmes being translated into reality in Asian countries that have different political systems, are at different stages of development and face different energy security and environment concerns? What are the challenges governments and industries face in nuclear energy development in these Asian countries? These are some of the questions explored in this book.

The drivers for the recent interest in nuclear power are of a similar nature across countries. They include growing energy demands, concerns over securing energy supplies, the increasingly volatile price of fossil fuels and global environmental concerns. Every argument for nuclear energy has its powerful counter-argument. Rising energy demand can be addressed by improving energy efficiency and conservation. Energy security can be provided and greenhouse gas (GHG) emissions reduction can be achieved by increasing the share of renewable energy sources. No policies can be made on nuclear energy development without taking into consideration the arguments of both sides. How these arguments are balanced in each country will decide whether and at what speed its nuclear energy programme will develop.

Countries initiated their nuclear programmes under different circumstances and for different reasons. India, for example, started its civilian nuclear programme long before all other Asian countries; yet when its weapons programme overwhelmed its civilian one, nuclear energy development became a contentious international issue and a victim too. China started its nuclear development as a weapons programme that developed into an energy programme after reforms started in the late 1970s. South Korea and Taiwan both developed their nuclear energy programmes in the aftermath of the world oil crisis in the 1970s and under military authoritarian regimes when little opposition was raised; later, anti-nuclear movements became the catalysts for democratic movements. Since then, their nuclear energy development has been subject to increasing public scrutiny and opposition too. Japan's nuclear energy programme was initiated and developed with concerted efforts of governments and industries with little opposition primarily because of its limited energy endowment. After over three decades, Japanese nuclear energy development faces quite different challenges, of which accumulated radioactive nuclear waste tops the list.

This book provides an understanding of why and how five countries in the Asian region – Japan, South Korea and Taiwan, China and India – have initiated and developed their nuclear energy programmes and what challenges they face today. Contributors seek to explain whether the nuclear energy development in each country was driven by the low energy resource endowment, a desire to pursue international prestige, concerns of national security, environmental pollution or economic development in general.

In all five Asian countries, a combination of reasons has been driving their nuclear energy development. These different concerns have shaped the way a country's nuclear energy programme has been developed. For example, when countries are poor in energy endowment, as is the case in Japan, South Korea and Taiwan, nuclear energy development could gain substantial political support from governments and the public. When countries have other energy alternatives, such as China and India with their abundant coal reserves, the nuclear industry has to compete with other sectors for resources (financial, material and human), political attention and public support. Consequently, its development can be slow and attract strong opposition from governments, industries and the public. When a nuclear programme is motivated by both energy and security objectives, however, as is the case in India and South Korea, governments are often able to allocate substantial resources to the programme with limited public opposition.

Different motivations behind the initiation and expansion of nuclear energy programmes shape, and are shaped by, the players – governments, industries, the military/scientific community, the public, and particularly the interactions between them. The five Asian countries under study have different political systems and in the past four or five decades all have gone through significant political changes. Japan, South Korea and Taiwan have been seen by many scholars as examples of 'developmental states' where 'a robust and coherent state apparatus facilitates the organisation of industrial capital; an organised class of industrialists facilitates a joint project of industrialisation, which in turn legitimates both the state and industrialists' (Evans 1995: 228). In China and India, 'nuclear nationalists' and 'nuclear strategists' may disagree on *how* to develop their nuclear energy programmes, but there seemed to be a consensus that developing sophisticated nuclear capacity is an indication of their scientific and technological prowess which is equated to social success (Nayar 1983; Chellaney 1991). This adds a measurable weight to their international position, brings them to the top of the 'civilised' world, validates the potency of their defence and technological capabilities, and brings recognition and respect from friend and foe alike (Lewis and Xue 1988; Chengappa 2000).

By weaving together the driving forces behind nuclear energy programmes and players, the following chapters aim to document the dynamics of nuclear policy development in these Asian economies. Experience of nuclear energy development in the first-generation nuclear states can shed light on the key issues and challenges the newcomers have to deal with, because many issues involved are similar (Chapter 9).

Holding more than a quarter of the world's uranium reserves, Australia faces different challenges: how to take advantage of the rising interests in nuclear energy, especially in its neighbouring states; how to ensure its market share while securing nuclear non-proliferation; and more important, how to convince the public that uranium mining and milling would not cause environmental problems in their country (Chapter 10).

This book consciously takes a specific approach and tells only one 'story', which is a story that is told by nuclear scientists, nuclear engineers, industry regulators and those interested in nuclear energy development. There are other different nuclear stories that could be told by those who are interested in climate change, non-proliferation, energy market competition, or national industrial or technological policies. Their narratives would each be very different from those presented in this book. It is not a question of who is right or wrong, but who tells the story and what the focus is.

In the following sections, we will first explain the common motivations behind the current drive for nuclear energy development; we will then present a brief discussion of other narratives that no government can ignore in deciding nuclear policies; and finally we will outline the common challenges these Asian countries face.

Rationales for nuclear energy development

Countries are motivated to start and expand their nuclear energy programme for a variety of reasons. The more common ones are:

Rising demand for electricity – no country can achieve social and economic development without providing its citizens with access to a stable and reliable supply of electricity, which itself is an indication of 'development'. The more developed a country is, the higher electricity consumption per capita it has. The average electricity consumption per capita in OECD countries was 4608 kWh (67 per cent higher than the world's average) while that of Asia was 705 kWh (26 per cent of the world's average) in 2007 (IEA 2009b). In OECD countries, electricity is taken for granted and there is a 100 per cent access rate no matter how remote the areas. In many developing countries, providing people with access to a reliable and adequate electricity supply is a serious challenge, and in those where energy resources are either limited or unevenly located, nuclear is increasingly argued to be an alternative to supplement other sources. To be more specific, roughly 22 per cent of the world's population still do not have access to electricity and in 2008 this represented 1.5 billion people, the poorest of the poor in the world (IEA 2010: 12). In India alone, about 400 million people (exceeding the total population of Western Europe) do not have access to electricity and their right to vote constantly reminds governments of their needs and demands.

Moreover, countries in the process of industrialisation and urbanisation often face much higher growth rate in energy consumption, including that of electricity. At the peak of its development between 1960 and 1974, an average annual growth rate of electricity consumption per capita in Japan exceeded 10 per cent, which was much higher than that of many European and North American countries. Since 1973, the growth rate slowed down considerably in all OECD countries, including Japan, yet except South Korea, whose average growth rate was above 10 per cent (IEA 2009a: I.13). By the 2000s, Japan, South Korea and Taiwan were well over the peak of industrialisation and urbanisation and their electricity consumption per capita far exceeds the world average, with 367 per cent in Japan, 202 per cent in South Korea and 375 per cent in Taiwan. Consequently, their average annual growth rate dropped to below 2 per cent. In China, however, rapid growth took off only in the 1990s and currently its electricity consumption per capita is about 77 per cent of the world's average and 24 per cent of that of the OECD countries. Electricity consumption per capita falls behind the world's average in India (19 per cent) where more than 35 per cent of the population do not have access to electricity. Meanwhile, the world's two most populated countries are in their process of industrialisation and urbanisation, with nearly 200 million people in China, for example, having moved to urban areas in the past 15 years. 'The current pace of migration of about 15 million people per year moving into the cities is likely to continue for another 15 to 20 years' (Lieberthal 2009: 7). Urbanisation and industrialisation demand increasing electricity supplies, which 'grew by over 14 per cent per year between 2000 and 2007', and is expected to increase by 75 per cent between 2007 and 2015, and almost triple by 2030. India's electricity demand will grow at 5.7 per cent annually between 2007 and 2030, 'the highest in the world' (IEA 2009b: 97). It is not a surprise that in China, India and some other countries, such as Malaysia and Vietnam, governments see nuclear energy as a viable and supplementary source to meet rapidly rising demands for modern energy.

Limited natural energy endowment – all five Asian countries face serious challenges of limited energy resources and this has always been a powerful explanation for a country's choice of nuclear energy, as in France. Over 90 per cent of energy is imported in Japan, South Korea and Taiwan, where high energy dependency was a powerful driving force behind the initiation of their nuclear programmes. The two oil crises in the 1970s and early 1980s only highlighted the urgency and the need to diversify electricity generation. A sense of energy insecurity derived from its dependence on energy imports did not emerge in China until the early 2000s, when rapid expansion of thermal power generation in the previous two decades had led to serious concerns about the depletion of the country's abundant coal. This may partially explain its slow nuclear energy development in the 1980s and 1990s and the urgent push for its expansion in the 2000s. Like China, India has abundant coal reserves, but good quality coal has always been in short supply. To diversify energy sources while meeting rising demands, China and India are developing every alternative – nuclear as well as renewables, from hydro, solar, wind, to biogas.

Climate change – in the past decade or so, pressure to mitigate environmental pollution as the result of fossil fuel combustion has been one of the main justifications for countries to rush into nuclear development. The energy sector worldwide accounts for 84 per cent of global CO_2 emissions and 64 per cent of the GHG emissions. If there is a positive correlation between GDP per capita and CO_2 emissions per capita, China and India are facing an immense challenge to increase their energy supplies without incurring the same degree of GHG emissions as other developed countries did during their industrialisation and modernisation (Table 1.1). Their dependence on coal for over half of their total primary energy consumption and over 70 per cent of their electricity has had a heavy toll on the environment and climate change.

China is already suffering the serious environmental consequences from its heavy reliance on coal to generate electricity (about 80 per cent of generation capacity is thermal) that has taken its toll on human life, health and the environment. A 2007 World Bank report, 'The Cost of Pollution in China: Economic Estimates of Physical Damage', estimates the total cost of air and water pollution at about 5.8 per cent of its GDP annually; other scholars raised the direct cost of pollution damage to China's economy to 8–13 per cent of GDP. In human costs, an estimated 750,000 people die in China of pollution-related illness every year (Schwartz 2008). Pollution also affects China's neighbours.

Environmental pollution and GHG emissions in India are not as serious problems as those in China. Yet, there is a growing concern about their impacts, with more than 70 per cent of its electricity from thermal power plants. To avoid the path China took in the past three decades (providing access by adding 400–500 GW coal-fired generation capacity), India is looking for all alternatives, of which nuclear is only one. Even Japan, where the record of its energy efficiency is one of the world's best, sees its nuclear energy capacity as a way to deal with the energy-related climate change

Table 1.1 Status as emitter of CO_2 per capita, 2007

Rank	Country	$GDP per capita	CO_2 emissions per capita (t)
20	South Korea	27,100	9.9
23	Japan	34,303	9.6
59	China	5,500	4.6
108	India	2,728	1.2
World average		10,156	4.4

Source: IEA (2009b: 177).

issues. How the risk of climate changes is calculated in energy policy making will shape the choice of energy sources in these countries.

Technological development – the nuclear industry is technology-intensive and its development tends to have spill-over effects on the country's industrial development and enhance the productivity of capital, labour and other factors of production. It is, however, dominated by a few Western conglomerates, which control nuclear fuel, reactor and support technologies: the French Areva, the American Westinghouse (77 per cent owned by the Japanese Toshiba), the joined American-Japanese General Electric-Hitachi and Atomic Energy of Canada Limited (AECL). For these Asian countries, developing the technology and technical capacity is essential for both domestic and international concerns. The dual nature of nuclear technology has allowed countries to use it in medicine, agriculture and national defence. Using the nuclear energy programme to drive broader economic and technological development is a powerful motivation for a country's nuclear energy development, which in turn shapes technology diffusion and facilitates the development of indigenous engineering capacity (Chapters 7 and 8). Mastering advanced technologies and developing technological capacities are also promoted in these Asian countries so that they can compete in international nuclear energy markets, as demonstrated in the 2009 deal, with which South Korea would build 4 nuclear reactors in the United Arab Emirates (UAE) with a price tag of US$20.4 billion. Achieving technological prowess has been the consistent objective for all five countries in this study not only to satisfy their domestic development but also to become internationally competitive exporters in advanced industries, as they did in automobile and other electronic industries.

National prestige – nuclear development has been seen as a symbol of national prestige and standing in the international community. It is also a serious consideration as far as national security in Asia is concerned. The American nuclear and security protection for Japan, South Korea and Taiwan has shaped their current nuclear energy programmes. We are now seeing perhaps the last major attempt to reduce the number of nuclear weapons by the major nuclear weapon states: Russia and the USA. This raises particular strategic questions for Japan and South Korea that may in turn affect the direction of their nuclear energy development. For China and India, to what extent national security, the national prestige of being a nuclear power or simply self-confidence are taken into account in explaining their nuclear energy development is important because those issues decide which groups of players – energy or nuclear – have a crucial input in their nuclear energy decision making.

These motivations behind nuclear energy development are common in all countries but they assume different levels of importance at different historical periods and in different countries. In the 1970s, when the first wave of nuclear energy development started, energy security was of paramount concern in countries such as Japan, South Korea and Taiwan where a large amount of resources were allocated to nuclear energy programmes with little domestic opposition. Meanwhile, nuclear energy programme was also pursued in South Korea for both national security and energy reasons (Pollack and Reiss 2004). Diversifying energy sources remains a key motivation in Japan, South Korea and Taiwan. The issues of national prestige and security drove the nuclear programme in China and India (Hart 1983; Lewis and Xue 1988; Chakravarty 1992). In the 2000s, energy security and environmental concerns became the overwhelming motivations for China to expand its nuclear generation capacity, while in India the nuclear weapons programme remains a key issue for both the government and the nuclear community. Finally, for Japan and South Korea, capturing the world's market in nuclear reactors and in nuclear engineering has been recently added to the objectives (Chanlett-Avery and Nikitin 2009; Holt 2010). Behind each set of rationales for nuclear energy development is a group of players whose role in policy making is part of the nuclear politics in a given country. In China, for example, the military was part of the initial drive for civilian nuclear programmes in the late 1970s and 1980s because reform threatened its privileged position of guaranteed government budget allocation. To survive, it needed to expand, and nuclear energy development offered this opportunity. This is no longer the case, however, as electricity generation companies and provincial governments are now pushing for nuclear expansion. In South Korea, for example, industries were initially weak and it was the government that drove the programme by adopting a coherent national strategy with its targeted allocation of resources to support national industries, of which nuclear was an important component. Later, it was the coalition of its industrial conglomerates and the government that made its nuclear industry internationally competitive. In Taiwan, the rise of the greens and other non-government organisations (NGOs) broke up the monopolised decision making of nuclear energy and introduced different sets of politics into the debate. In Australia, anti-nuclear forces remain dominant even after three decades and despite the emergence of concerns about climate change.

Policy changes

This book documents the changes that have taken place in the nuclear energy policy making of the five Asian countries, as well as in Australia and OECD countries. We live in the present; but the past shapes our thinking, influences our selection of choices and guides how we will act. Even though the past does not determine our present or the future, it is important to deconstruct the past in order to understand the interaction between developing new ideas and changes in formal and informal institutions. This is the precondition to understand what options we have and what the likely choices we may select. By examining why and how the nuclear energy programme has evolved in each case, we will be able to identify the players, their roles and their interactions.

There is one significant difference between the public attitude in Asia and in Europe. In Asia, nuclear energy represents the future and a viable alternative energy source to deal with multiple challenges. In Europe, it signifies risks. For many in Europe, (a) nuclear energy is capital intensive and expensive and resources could be better used to develop other low-carbon energy alternatives; (b) nuclear power plants require complicated technologies and qualified people to design, construct, operate and manage nuclear power plants, all of which are in short supply in developing countries; (c) nuclear ambitions of 'non-democratic' and non-Western countries highlight proliferation risks; and (d) nuclear waste management remains an unsolvable issue. In sum, nuclear energy is a risk not worthwhile pursuing. This attitude was to a large extent shaped by the development of Europe's nuclear industry and particularly the Chernobyl nuclear disaster and the Three Mile Island accident. The public opinion in Europe would have been so different 'if the industry had worked from the start to minimise fear as hard as it has worked to minimise danger' because public thinking and their fear are 'socially constructed perceptions and away from the world of quantitative or "true" risk' (Nuttall 2007: 226).

Just as Chernobyl and Three Mile Island shaped the public opinion, attitude and consequently the public policy in Europe, the successful nuclear power programmes in France, Japan and South Korea shape the general public attitude towards nuclear energy in China, India and other Asian countries and are reinforced by their lack of energy endowment, a sense of energy insecurity and immediate suffering from environmental pollution as the result of heavy reliance on coal. Such perceptions in each case set the parameters within which governments make their policies. Understanding how the attitudes were developed and policies were made in Asia is one main objective of this book.

Nuclear energy develops within a broader national political and economic environment, and a pre-existing pattern of political economy in each place shapes the direction, the way and the speed at which nuclear development takes place. For example, in Japan, South Korea and Taiwan, one would expect a close relationship between government agencies and industries, whether through the so-called 'revolving door' as in the case of Japan, where those in the nuclear industry alternate between government agencies and utility companies, or in South Korea where a powerful corporation was supported by 'sectorally specific financial incentives and use of government procurement' (Evans 1995: 212). In Taiwan, even though the state-owned Taipower was 'long led by a stable cadre of technocrats, it had considerable day-to-day operating independence, and it was always subject to oversight by the executive and the ruling party' (Haggard and Noble 2001: 257). Democratisation processes introduced 'more open oversight mechanisms that provide opportunities for legislators and interest groups to participate' in energy policy making, but they also 'reduced the influence of cronies and constituents in the state sector' (Haggard and Noble 2001: 289).

Universal access to stable and reliable electricity is often taken for granted when economies have reached a developed stage; however, economies cannot develop without electricity in the first place. When a country is still developing, its government must balance competing demands for resources – financial, material and human – from various industries, societal groups and bureaucracies. Furthermore, in many countries, even in some old democracies, nuclear energy policy used to be an area where only nuclear scientists, energy specialists and government officials interacted. They were able to seal off the decision-making process, because energy is a complicated technical matter that they alone were qualified to deal with. In general, the public did not care where their electricity came from so long as when they flipped a switch a light came on.

The nuclear community and governments added another layer of secrecy to nuclear energy because of the dual use of technology. This changed, especially after the Three Mile Island accident in 1979 and the Chernobyl disaster in 1986, and with increasing global economic integration. The public were worried about the safety of nuclear power plants; environmentalists raised concerns about nuclear waste disposal; local industries demanded their share of opportunity in nuclear energy development; and security specialists drew attention to concerns about nuclear proliferation. The nuclear energy world has become a much more complicated field where a wide range of interests compete for attention and agenda.

The next chapter provides an overview of the issues involved in nuclear energy development in Asia. These countries face many similar challenges, including, for example, obtaining access to finance to meet the demand of intensive capital investment, fuel services supply and waste management. Public acceptance is a necessary condition for nuclear development in all countries, but public opinion can vary significantly from country to country depending on the availability of electricity, alternative energy sources and finance. Public opinion also differs from one country to another because of the urgency of environmental pollution concerns. This general discussion provides a context within which case studies of five countries are discussed. These five case studies cover nuclear energy development in China, Japan, India, South Korea and Taiwan. In each chapter, the contributor seeks to explain: (a) what the government policies are regarding nuclear energy development; (b) who are the main players in nuclear energy making; (c) what their interests are; (d) how different interests interact in shaping nuclear energy policies, particularly those on resources allocation and technology adoption; and (e) what the prospects of future development are.

These case studies outline the similar concerns and motivations that are behind their nuclear energy programmes, but they also highlight the different challenges each country faces. For example, Sang Dongli explains the more recent development in China and why and how the government tries to use nuclear energy expansion to deal with some of the most 'difficult-to-reconcile objectives: adequate energy for long-term economic growth, energy that can be secured without exposure to undue geopolitical risk, energy supply and utilisation consistent with long-term public health, and energy supply flexible enough to meet rising popular expectations for public and private goods' (Steinfeld 2008: 133). Toshihiko Nakata focuses on the physical constraints of nuclear power plants in meeting the electricity demand. Jeff Graham focuses his discussion on the efforts made and challenges faced by the Japanese nuclear community to build a full nuclear fuel cycle. The driving force behind this development is a combination of energy security and environmental concerns. Building a full nuclear fuel cycle has created its own security and environmental concerns.

Nuclear energy development in South Korea is one of the best examples of a consistent national commitment, coherent development strategy and targeted government support in its industrialisation and modernisation. Yang and Xu show how South Korea has moved from technology borrowing to its imitation, adoption, localisation and standardisation and has built an internationally competitive industry.

India started its nuclear development as a civilian programme before all the other Asian countries that are covered in this book. It was then, however, mainly denied access to technology because of its refusal to participate in the non-proliferation regime. Despite this, Lavina Lee argues, 'India managed to develop a truly indigenous nuclear energy capacity and has made progress on its long held goal of establishing a fast breeder programme.' As a professor of nuclear engineering, Min Lee provides a comprehensive discussion on the nuclear energy programme in Taiwan, covering its history, financing, safe operation, public acceptance and the politics involved. The politics involved in the fourth nuclear power project in Taiwan is in clear contrast with that of the previous three projects which were pushed through so quickly and so easily without no public input and no opposition. Party politics and public involvement in a democratised society mean that the government has to seek a wide range of support to get any power station on line.

In discussing the nuclear development among OECD countries, Per Högselius points out similar issues and challenges that both 'old' and 'new' nuclear powers have faced in their development. The chapter particularly focuses its discussion on the collapse of the nuclear industry in OECD countries after the Chernobyl disaster and how it is reviving under the pressure of climate change in Europe and North America. Nuclear energy development and expansion in Asia cannot happen without adequate supply of uranium because none of them have a large quantity of uranium reserves. This development provides special challenges to uranium suppliers, such as Australia. Stuart Harris asks how Australia is responding to that renewed interest and how it seeks to balance its economic and environmental interests against the implications for its traditional nuclear non-proliferation activism. The chapters by Per Högselius and Stuart Harris provide a broader context for us to understand nuclear energy development in Asia.

The International Atomic Energy Agency (IAEA) and International Energy Agency (IEA) are calling for not only a 'technical breakthrough' but also 'active, perhaps even revolutionary, government intervention' to replace the current 'dirty, insecure and expensive' energy with a 'clean, clever and competitive' one (IAEA 2006; IEA 2006). At the same time, anxieties are rising about the quality and safety of nuclear power plants. This is a particular concern for developing countries that may not have the necessary human capacity to accommodate rapid nuclear energy expansion, or an operational legal and regulatory regime to ensure the quality and safety of nuclear power plants. Given that the nuclear industry is a truly global industry, it is important to understand the challenges it faces in those countries where nuclear power programmes are expanding quickly.

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2
The Politics of Nuclear Energy in Asia

Xu Yi-chong

Introduction

Nuclear energy is politically sensitive. For its proponents, it is clean, highly efficient and the only alternative to fossil fuels in providing a base supply of electricity. For its opponents, however, nuclear energy is nothing but trouble – a symbol of war and weaponry, dangerous and highly risky, and it creates environmental problems not only for the current generation but the future too.

What is remarkable in this highly emotional debate is the general division between developed and developing countries. In many developed countries, such as Australia, where 22 per cent of the world's known recoverable uranium resides, the public and politicians prefer not to discuss the issue because it is too divisive. In other countries, such as Belgium and Germany, the decision has long been made to phase out existing nuclear power plants. Even in those countries where the government recently made a decision to revive its nuclear energy programme, such as Britain and Sweden, the debate is as intense and intensive as ever. In contrast, in developing countries, large and small, rich and poor, from Africa and Asia to the Middle East, nuclear energy is presented as a viable alternative to fossil fuels to meet their rising demands for modern energy while curtailing environmental pollution from energy production.

While the public may be divided on the issue, governments in developing countries seem to be speaking with the same voice. At the International Atomic Energy Agency (IAEA) Ministerial Conference on Nuclear Energy for the 21st Century, held in Beijing in April 2009, delegates from energy or science and technology ministries in both developed and developing countries – from Cameroon to Nigeria, from Chile to Argentina, from Jordan to Saudi Arabia, from Finland to Belarus, and in Asia from Bangladesh to India, from Malaysia to Vietnam, from China to Japan – all outlined their plans to expand their current nuclear energy programme or to start one.

Table 2.1 Nuclear power plants under construction by country in 2010

Country	No. of units	Total MWe
Argentina	1	692
Bulgaria	2	1,906
China	21	20,920
Finland	1	1,600
France	1	1,600
India	4	2,506
Iran	1	915
Japan	1	1,325
Korea	6	6,520
Pakistan	1	300
Russia	8	5,944
Slovak	2	810
Taiwan	2	2,600
Ukraine	2	1,900
United States	1	1,165
Total	54	50,703

Source: IAEA (2010).

Asian countries are more active than many in other continents in expanding or developing their nuclear energy capacities. In 2009, worldwide construction was started on 11 new reactors, 10 of them in Asia. China alone hosted 9 reactors. By 2010, a total of 54 reactors were under construction worldwide and Asia hosted 36 of them (Table 2.1). Three of the six countries that will have the largest installed nuclear capacity in the world by 2020 will be in Asia – China, Japan and South Korea (NEA 2008: 52).

The justification for nuclear expansion and development has two components: one is that there is a close and positive correlation between energy supply and development – that is, no development can take place without energy and poor countries cannot achieve their UN Millennium Development Goals (MDG) unless a large number of citizens have access to electricity. Given that many Asian countries do not have sufficient fossil fuel resources in their territory, the uncertainty of supply and price of natural gas and oil in global markets makes diversification of energy sources crucial for energy security. The other justification for nuclear power is climate change, which is occurring because of CO_2 emissions from fossil fuel burning. The Inter-governmental Panel on Climate Change (IPCC) data show that emissions from power plants are the largest (27 per cent) and fastest growing contributor to CO_2 releases. In developed countries, according to some scientists, 39 per cent of 'the energy forms that produce CO_2 is used for generating electricity, 36% is used for generating heat for buildings and industry, and 25% is used in transportation' (Baruch 2008: 112). Since neither energy for heating nor energy for transportation account for a large share of total primary energy consumption in developing countries, their main challenge is how to expand electricity generation capacity while limiting CO_2 emissions. Given that nuclear energy has relatively low carbon emissions (virtually CO_2-free), it is argued that nuclear science and technology offer one of the possible solutions to the unsolved conundrum of combining economic and social development with energy security and environmental sustainability.

For many developing countries, therefore, the question is not whether they want to build or expand the number of nuclear power plants (NPPs), but whether they will be able to do so, at what speed this development will take place, what technology they will adopt and how they can achieve a rapid development or expansion without undermining the general economic and social development in the country or triggering nuclear weapons proliferation across countries. The evolution of energy supply (quantity as well as source) depends to a large extent on the policies adopted by governments regarding general economic and social development and the decarbonisation in energy supplies to address climate change issues. It is important to understand the challenges these countries face in trying to achieve their desired objectives, the different policy options available and government capacity in making the choices and dealing with the challenges.

Rising energy demands

The population boom, poverty, environmental problems and energy security are the colossal challenges many developing countries are facing, especially in Asia. Countless studies have shown that there is a positive correlation between energy consumption and economic and social development. In 2006, OECD countries, with 10 per cent of the world's total population, consumed more than 47 per cent of primary energy used worldwide; in contrast, Asia (excluding China), with 32.4 per cent of the world's population, consumed 11.3 per cent of the primary energy used worldwide. The gap in electricity consumption per capita was even larger between rich and poor countries, in 2006 with an annual consumption per capita of 8381 kWh in OECD countries but only 667 kWh in Asia, less than 8 per cent of that in OECD countries (IEA 2008: 48–49). In OECD countries, even in remote areas, citizens have access to stable and reliable supplies of electricity. Any blackout or brownout, even if it lasts for a few hours has the potential to bring down a government not only because electricity is essential for modern economy and life but also because electricity is taken for granted by the public which sees it as the duty of governments to ensure its reliable supplies. This is far from the case in many developing countries.

According to the International Energy Agency (IEA), about 1.4 billion people in the world still do not have access to electricity. In sub-Saharan Africa, nearly 75 per cent of the population do not have access to electricity. In

Table 2.2 ASEAN electricity access by country, 2008

Country	Electrification rate (%)	Electricity consumption per capita (kWh)[1]	Country	Electrification rate (%)	Electricity consumption per capita (kWh)[1]
Brunei	100	8,209	Myanmar	13	98
Cambodia	24	112	Philippines	86	588
Indonesia	65	589	Singapore	100	8,186
Lao	55	N.A.	Thailand	99	2,079
Malaysia	99	3.493	Vietnam	89	799

[1] Data is from IEA (2010).
Source: IEA (2009: 561).

South Asia, the electrification rate reached 52 per cent by 2005 and this still left 580 million in rural areas and 126 million people in urban areas without access to electricity. In the rest of the Asian and Pacific region (Table 2.2), even though on average the electrification rate had reached 89 per cent by 2005, 182 million people in rural areas and 41 million people in urban areas remained without access to electricity (IAEA 2006: 156). In India alone, the number of people without access to electricity exceeds that of the total population in Western Europe.

History has shown that no economic and social development can take place without providing ordinary citizens access to electricity. The OECD has set electricity consumption of 4,000 kWh per capita as the threshold level below which 'social indicators such as life expectancy and educational attainment are becoming significantly lower than in countries having access to more electricity supply' (NEA 2009: 21). On average, Asia has electricity consumption per capita of only 667 kWh, less than 20 per cent of the threshold. Rapid expansion of electricity supplies is not only necessary but will also place great pressure on resources, both financial and natural, as well as on environment and climate change.

According to the IEA, primary energy demand in the world will grow by 40 per cent between 2007 and 2030, and just over 90 per cent of this increase will come from non-OECD countries. In the same period, electricity demand will grow by 76 per cent, growing at an annual rate of 2.7 per cent in 2007–15, slowing to 2.4 per cent in 2015–30. Over 80 per cent of the growth in 2007–30 is in non-OECD countries where an annual growth rate will exceed 5 per cent in 2007–15, slowing to 3.3 per cent in 2015–30. Coal-based electricity generation will be 5 per cent higher by 2030, 'with OECD reduced by 8% and non-OECD Asia increased by 10%' (IEA 2009: 98). Particularly, coal-fired generation will grow by 2.5 times in China and by 3.5 times in India in the period of 2007–30. While fossil fuels will remain the main

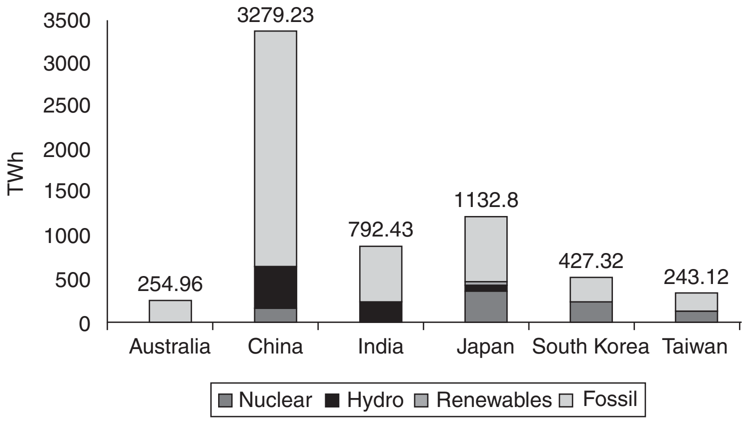

Figure 2.1 Electricity production by source, 2007
Source: IEA (2009), *Electricity Information 2009*. Paris: OECD, pp. II.8, II.10.

electricity sources, many Asian countries have limited natural energy endowments to meet their rising demands. With about 20 per cent of the world's population, China has 1.3 per cent of the world's proven oil reserves, 1.1 per cent of the natural gas and 13.5 per cent of the coal. India, with 17 per cent of the world's population, has 0.4 per cent of the world's proven oil reserves, 0.6 per cent of the natural gas and 6.7 per cent of the coal. Indonesia fares no better. With almost 4 per cent of the world's population, Indonesia has 0.4 per cent of the world's proven oil reserves, 1.7 per cent of the natural gas and 0.5 per cent of the coal (BP 2010). Consequently, fossil fuels (mainly coal) are the main sources for electricity generation: 92 per cent in Australia, 61 per cent in Japan, 62 per cent in Korea, 78 per cent in Taiwan, 83 per cent in China, 88 per cent in Indonesia and 81 per cent in India (Figure 2.1).

Together Southeast and East Asian regions have higher reliance on fossil fuels to generate electricity than other regions in the world (Table 2.3). Heavy reliance on coal for electricity generation has already taken its toll on coal reserves, which are depleting rapidly, and, more importantly, on the environment. With a growing share of electricity in energy consumption in developing countries, CO_2 emissions from the power sector will, by 2030, grow by 131 per cent from the 2006 level. China and India alone will account for 58 per cent of the global increase in CO_2 emissions from power generation because of their heavy reliance on coal. China has already become the major contributor to global CO_2 emissions, contributing 20.2 per cent of the world's total CO_2 emissions by 2006, compared with just 5.7 per cent of the world's total CO_2 emissions in 1973. It is not only CO_2 emissions that threaten people's health and their livelihood, but also other substances of environmental pollution such as SO_x or NO_x, and

Table 2.3 Fuel shares for electricity generation in 2006 (per cent)

	Thermal	Hydro	Nuclear	Renewables
North America	65.71	14.53	18.99	0.77
Latin America	38.28	58.31	2.61	0.81
Western Europe	52.32	15.86	29.14	2.68
Eastern Europe	64.95	17.21	17.80	0.05
Africa	80.01	17.74	1.84	0.41
Middle East and South Asia	82.42	15.51	1.57	0.50
Southeast Asia and Pacific	88.17	10.73		1.10
Far East	75.65	12.50	11.52	0.33
World	73.5	6.9	18.2	1.4

Source: IAEA (2007b).

indoor air pollution caused by burning traditional biomasses such as crop residues and animal dung. This is the major difference between developed and developing countries on environmental and health issues: ‘Developed countries have for the most part eliminated the main sources of local and regional pollution and their main environmental concern is climate change,’ while many developing countries ‘experience immediate losses from smog and acid deposition’ (Toth 2008: 15).

Two fundamental ways of dealing with climate change are by improving energy efficiency and increasing the share of renewable energy. With very low-level energy consumption per capita and low levels of industrialisation and urbanisation in many developing countries, an improvement in energy efficiency will help deal with environmental challenges, but will not reverse the upward trend of energy demands. Most countries are committed to increasing their share of renewable energy in their total energy consumption. Wind, sun and rain have always been sources of energy. Nonetheless, ‘wind, sun, and rain suffer from intermittency’ (Baruch 2008: 113), and developing their capacity not only is expensive but also takes time.

While the load factor (utilisation rate) for coal-fired thermal generation power plants is about 70–90 per cent and for NPPs is 80–90 per cent, that for wind power is about 30 per cent and only 15 per cent for solar. It takes only a few square kilometres of space to build a one-gigawatt (GW) coal-fired or nuclear generation capacity, while it takes hundreds of square kilometres to build the same sized solar or wind capacity. Even with advanced technologies that improve the availability of solar power from the current 15 per cent to 36 per cent, to generate one megawatt of electricity per year ‘would require 40 acres of photovoltaic cells’ (Baruch 2008: 113). Others do not agree with this assessment, arguing that, for example, much of the photovoltaic (PV) solar capacity could be on rooftops, so involving no extra land use, or that wind turbines only take relatively small areas themselves so that the land around them can still be used for farming (Lovins 2009).

These alternative suggestions about solar and wind generation capacity may be appropriate for Europe and North America; it is however difficult to see how they could be adopted in many Asian countries where the population density limits the capacity of placing solar panels on rooftops. Nor are there large spare pieces of land for wind farms except in remote regions. Furthermore, given their low availability rate, wind and solar power need grid balancing backup capacities. Building extensive transmission grids and additional backup generation capacity will significantly increase the costs of providing access to modern energy. In Europe, where access to electricity is universal, there are proposals to deal with the local variability problems of renewable energy by, for example, building pan-EU grid interconnections to widen the geographical footprint and allow for grid balancing across a much wider area (Elliot 2009, 2010). In Asia, with vastly larger distances and populations, the first and foremost priority for all governments is to provide people with access to adequate and reliable electricity supplies as quickly as possible in an environmentally sustainable way and with assured technology. It is consequently no surprise that many of them, such as China and South Korea, not only are spending massive funds on developing renewable energy, but also have made concrete plans to build and expand their nuclear energy programmes.

Nuclear programmes

Currently, nuclear power meets less than 10 per cent of the world's total energy needs. It nonetheless provides about 15 per cent of the world's electricity, a share similar to that of hydropower, which is much more widespread than nuclear power (Table 2.4). Only 30 countries have NPPs in operation and those countries where nuclear electricity accounts for large shares of total electricity supplies are all developed countries:

Table 2.4 World energy use by fuel type, 1980–2005 (per cent)

	1980	**1985**	**1990**	**1995**	**2000**	**2005**
Solids	27.7	29.8	27.4	25.7	22.7	25.7
Liquids	42.8	36.9	36.5	34.9	34.8	33.7
Gases	19.2	20.2	21.4	22.5	23.9	23.2
Fossil fuels (sub-total)	89.7	87	85.3	83.2	81.4	82.7
Biomass	5.5	5.7	6.2	7.7	9.4	8.5
Hydro	2.2	2.3	2.3	2.4	2.4	2.3
Nuclear	2.4	4.7	5.9	6.2	6.4	6.1
Renewables	0.2	0.3	0.4	0.4	0.5	0.5

Source: IAEA (2007b: 6).

France 78 per cent, Belgium 54 per cent, Sweden 48 per cent, Switzerland 37 per cent, Finland 28 per cent, USA 19 per cent, UK 18 per cent and some transition economies in East Europe. Only two Asian countries join this list: Korea 39 per cent and Japan 30 per cent. Meanwhile, studying the general energy development, IAEA concluded that the share of fossil fuels in the world's total energy use declined from 90 per cent in 1980 to 82.7 per cent in 2005 and this 'decline in the share of fossil fuels was taken up by an increase in the use of nuclear power and biomass' (IAEA 2007b: 6). The use of nuclear energy increased faster than the total energy consumption.

This trend of replacing fossil fuels with nuclear energy did not happen in developing countries, which remain dependent on fossil fuels as their most important energy source. The heavy reliance on fossil fuels has caused serious concerns worldwide, especially among some developing countries that have been feeling the pressures of rising energy prices and the threats of climate change. When the price of oil, natural gas and coal doubled, tripled or even quadrupled after 2000, those countries that depended heavily on burning fossil fuels for their electricity generation started to look for alternatives to diversify their energy sources. The release of the report of the IPCC in 2000 put further pressure on these countries. Even though the IPCC has not taken a formal position on nuclear energy as an alternative, the UN Committee on Sustainable Development has acknowledged at various meetings that advanced technology is the key to dealing with environmental pollution and that whether and when to develop a nuclear energy programme is in the hands of individual states.

Since the early 2000s, according to the IAEA, more than 60 countries – mostly in the developing world – have informed the IAEA that they are interested in launching nuclear energy programmes. Of these, 12 countries are actively considering it. In the next 15–20 years, more than two-thirds of new NPPs will be built in developing countries, with Asia taking the lead (Table 2.5). In East Asia, China, Japan, South Korea and Taiwan have already had a well-established nuclear energy programme, and in 2008, China, South Korea and India each had six reactors under construction; Taiwan and Japan had two each; and Pakistan had one under construction (IAEA 2008: 52). In the Southeast Asian region, Vietnam was planning to build 8,000 MWe nuclear capacity and in Indonesia 2,000 MWe was planned. Malaysia, the Philippines and Thailand were discussing plans for nuclear energy programmes. In Indonesia, the government issued a national energy plan in 2000 which raised a nuclear energy option; a national Nuclear Energy Regulatory Agency (NERA) was consequently created in 2005. NERA then worked out a blueprint of nuclear energy development and planned to have its siting and construction approval before 2010. Even though the Indonesian president then rejected the plan, NERA is still actively promoting the development of nuclear energy in Indonesia. While nuclear energy is presented by many in the field as the 'only' clean energy that can be used as a base

Table 2.5 Asian nuclear reactor plans to 2030 (MWe)

	Operating	Construction	Planned	Proposed
China	8,587	12,100	35,320	94,000
India	3,779	2,976	9,760	11,200
Indonesia			2,000	4,000
Japan	46,236	2,285	17,915	1,300
Korea	17,716	5,350	9,450	
Pakistan	400	300	600	2,000
Thailand			2,000	4,000
Vietnam			2,000	8,000
Asia	76,718	23,011	84,495	142,000
World	372,220	39,948	131,145	299,405
Asian (per cent)	21	58	64	47

Source: Platts (2009).

supply, its development raises several challenges: (a) how to obtain its initial intensive investment and meet a high demand for human resources and advanced technology; (b) even though the cost of fuel for NPPs is low, how to secure nuclear fuel services without triggering nuclear weapon proliferation; and (c) how to manage and dispose of its radioactive waste. In addition, the potential of nuclear development needs to be kept in perspective. That is, even if governments' very ambitious expansion plans can be fully implemented, nuclear energy will provide only a minute share of total energy consumption in the near future, as in China where 60–70 GWe would meet just 4–5 per cent of the country's total energy consumption by 2020.

Access to finance and technology: two related issues

It is expensive to build nuclear energy programmes. How to finance them, what technology countries should adopt and how governments can balance the demands for financial and other resources while their countries are still developing economically and socially are all serious challenges for those countries looking to nuclear energy as an alternative to fossil fuels. In a lifetime cycle, nuclear power may be economically competitive. Financing it can be problematic. Developing electricity generation capacity involves intensive and sunk-capital investment. This is the case for all sources: thermal, hydro, solar and wind, as well as nuclear. Recently, several institutions, such as Massachusetts Institute of Technology (MIT), University of Chicago, IAEA and IEA, have conducted studies comparing the cost of electricity generated by NPPs with coal- or gas-fired thermal power plants, MIT's study in 2003 argued that:

> In deregulated markets, nuclear power is not now cost competitive with coal and natural gas. However, plausible reductions by industry in capital cost, operation and maintenance costs, and construction time could reduce the gap. Carbon emission credits, if enacted by government, can give nuclear power a cost advantage. (2003: ix)

In its recent updated study, the team at MIT showed 'there remains significant uncertainty about the capital costs, and the cost of its financing, which are the main components of the cost of electricity from new nuclear plants' (MIT 2009: 6). Since the early 2000s, there has been a significant rise in the upfront capital costs of constructing NPPs (about 15 per cent increase each year) because 'construction costs of all types of large-scale engineered projects have escalated dramatically' (MIT 2009: 6). This means that a single nuclear reactor with 1,000 MWe capacity would cost US$4 billion in 2009, doubling the 2003 cost (Table 2.6).

The oligopolistic structure of the nuclear industry in the world does not help in bringing down costs. In the past 20 years or so, the number of nuclear suppliers has significantly reduced – there are few reactor designers and few reactor choices. Currently, the worldwide nuclear energy sector is dominated by four major suppliers: Westinghouse from the USA with its AP1000, AECL from Canada with its CANDU 6, Areva from France with its EPR1000 and

Table 2.6 Costs of electric generation alternatives

	Overnight cost	**Fuel cost**	**LCOE**		
			Base cost	**w/Carbon charge $25/tCO_2$**	**w/Same cost of capital**
	$/kW	**$/mmBtu**	**¢/kWh**	**¢/kWh**	**¢/kWh**
MIT (2003) US$2002					
Nuclear	2,000	0.47	6.7		5.5
Coal	1,300	1.20	4.3	6.4	
Gas	500	3.50	4.1	5.1	
MIT (2009) US$2007					
Nuclear	4,000	0.67	8.4		6.6
Coal	2,300	2.60	6.2	8.3	
Gas	850	7.00	6.5	7.4	

Source: MIT (2009: 6).

Rosatom from Russia with its VVER. They offer mature technology and experience in constructing and operating NPPs, which either are in short supply or do not exist in many developing countries. Meanwhile, as plant size grew and as operational issues began to moderate the industry's confidence in the ultimate safety of the plants, more stringent safety requirements were imposed and the elegant simplicity of the original light water reactor (LWR) plants gave way to a complex layering of redundant safety and auxiliary systems. This has not only led to a rapid increase in costs, licensing delays, and construction and operation complexities, but has also made it difficult for others to duplicate the technology and standardise it in their domestic markets to bring down the cost.

Even though many in the field prefer to argue that investments in nuclear energy 'are subject to a common risk/reward standard since finance is globally fungible' (Besant-Jones and Glendenning 2000: 133), obtaining a large sum of financial capital has never been easy for developing countries.

This is one of the main challenges developing countries face in undertaking a nuclear energy programme – how to finance it. Demands on financial capital in developing countries are multiple and many countries do not even have the proper infrastructure to accommodate the NPPs because of the initial lack of capital. It is almost impossible to obtain sufficient finance from domestic sources. Multilateral financial institutions, such as the World Bank and the Asian Development Bank (ADB), do not offer financial assistance to build NPPs. A nuclear investment project involves long-term debt financing and this poses risks for both lenders and borrowers. Most developing countries are subject to pressure from the long construction period and high uncertainty of exchange markets. As the finance minister in Indonesia recently pointed out, many Southeast Asian countries learned hard lessons from the 1997 financial crisis and have imposed tight fiscal and financial disciplines on themselves because economic confidence is crucial in developing countries. Even if they could borrow from the international financial markets, the exchange rate uncertainty would not work to their advantage. Their governments would also have to consider how to balance the rising demands for capital in other areas and how to balance the demand for energy development and their country's macroeconomic conditions.

Finally, obtaining export credits from international nuclear vendors is an option, but this increasingly has its limitations as well. As more developing countries chase the same vendors for credits, the cost of borrowing goes up in the same manner as 'construction costs for nuclear power plants [go up] by increasing demand for scarce components that are necessary to build reactors (for example, specialised steel forgings)' (CBO 2008: 10). Furthermore, export credits normally come with conditions, which often limit the opportunities for domestic firms to become involved in the construction and operation.

Nuclear energy has a high requirement for technological and human resources. While the nuclear energy market is dominated by corporations producing large reactors with more advanced technology and better safety records, it is difficult for developing countries to adopt the technology of these large reactors when the electricity market is relatively small and its infrastructure has not been fully developed. Large NPPs with a capacity of 1,000 MWe will significantly exceed that of other types of power generation capacities in most developing countries and place great pressure on the infrastructure, particularly the transmission networks, which have to be strengthened at a time when demands for financial resources are high and rising. Given the nature of their 'natural monopoly', transmission grids worldwide are financed by governments. How to calculate power tariffs by including all of the investment (NPPs as well as other infrastructures) to reflect the real cost and to balance affordability is not an easy issue for governments to deal with. Adopting large and mature reactors also means low or zero participation of local industries in their construction and little participation of local technology and supply for maintenance.

The challenge for newcomers is that they need to look for mature and simple technology and proven reactor designs, with an electric power output appropriate to their existing infrastructure (especially their grid capacity) and their available human resources. The challenge for those that have already had capacity is to provide competitive reactor designs for the newcomers. The study carried out by the Nuclear Energy Agency (NEA) of OECD shows that the larger the capacity a reactor has, the lower the costs it incurs (NEA 2008), and there is little incentive for the nuclear conglomerates to invest in developing small- and medium-sized reactors. While the four conglomerates are competing for the global market, some newcomers are joining in to build larger reactors: South Korea has built its own model ARP 1400 after decades of introducing, adapting and upgrading the technology of French reactors.

The IAEA has been coordinating the development of small-sized reactors for their developing newcomers. It defines a small reactor as one with electricity output of less than 300 MWe and a medium-sized reactor as one with a capacity of 300–700 MWe. Currently, several countries have been able to build small- and medium-sized reactors; India has developed its own 300 MWe advanced heavy water reactors (AHWRs), Argentina has its integrated pressurised water reactor (PWR) of 25–300 MWe capacity, and China has its 300 MWe PWR. These new players in the world nuclear market have argued that developing countries should, and could, adopt these small-sized reactors as a bridging programme for their nuclear energy development because they are relatively inexpensive, and their smaller size also makes it easier to deal with transmission problems. Meanwhile, many of these new players are unable to offer export credits to those developing countries wishing to build their nuclear energy programmes. Even if these new players are able to provide finance for exports, they are competing with much larger and more mature manufacturers of reactors and the auxiliaries. In the coming decades, the nuclear sector will see increasing competition among the established and large vendors as well as competition between those who offer large and those who offer smaller-sized reactors. Since nuclear research almost everywhere depends on governments' allocation of resources, how does this affect the technology development and market competition for any coming nuclear renaissance?

Nuclear energy development cannot have a future until countries have built adequate human capital. In some countries, there are well-established education programmes in nuclear engineering, nuclear physics, mechanical engineering and related fields at universities and technical colleges. This is not the case in many developing countries. Investing in education often makes sense when long-term benefits are considered, but in the short term it is very difficult for governments to increase education spending when basic needs still have to be met.

Fuel supplies

One of the main arguments in favour of nuclear energy is that uranium is more widely available than other fossil fuels and therefore it can help countries secure their energy diversification. Furthermore, the high capital investment of NPPs can be compensated by the low fuel cost. 'A doubling of fuel prices would increase generation costs by about 40% for coal, 75% for gas and 4% for nuclear' (NEA 2008: 189). Finally, the uranium market has become a true global market as government intervention at the front end of the nuclear fuel cycle 'has decreased considerably from the high levels of the 1970s' (NEA 2004: 45). In 2006, for example, only Canada and South Africa produced sufficient uranium for their requirements and other countries depended on uranium imports to various degrees.

The uranium market, meanwhile, has had its ups and downs. In the 1980s and 1990s, while uranium requirements exceeded supplies, the gap was met after the Cold War ended by the secondary market with accumulated inventories and downgraded weaponry of highly enriched uranium (HEU). This led to a prolonged period of low uranium prices, which in turn 'led to the closure of all but the lowest-cost mining facilities, stimulated market consolidation and curtailed investment in exploration and mine development' (NEA 2008: 157). However insignificant the impact of fuel costs may be on the total cost of nuclear power, costs of uranium and nuclear fuel services all rose considerably as many developing countries were trying to develop or expand their nuclear energy sector. Since the early 2000s, the price of uranium has climbed rapidly from US$18/kgU in 2000 to US$52/kgU in 2005 and US$351/kgU in mid-2007, almost 20 times that of prices that existed less than seven years earlier.

Table 2.7 Global fuel cycle capability by country

Country	Conversion	Enrichment	Fuel fabrication	Reprocessing
Argentina	√		√	
Belgium			√	
Brazil	√		√	
Canada	√		√	
China	√	√	√	
France	√	√	√	√
Germany		√	√	
India	√		√	
Japan		√	√	(*)
Kazakhstan			√	
Korea			√	
Netherlands		√		
Pakistan	√	√	√	
Romania			√	
Russian Federation	√	√	√	√
Spain			√	
Sweden			√	
UK	√	√	√	√
USA	√	√	√	

Note: Japan had plans to begin reprocessing in 2008.
Source: NEA (2008: 57).

Uranium needs to be converted and enriched to be used to produce energy in a nuclear reactor. Globally, nuclear fuel cycle services, such as enrichment and fuel fabrication, are readily available with excess capacity and intense competition, but only a few countries worldwide have full nuclear cycle capability and can provide such services (Table 2.7). The international community seems determined to allow nuclear energy expansion but at the same time to restrict nuclear fuel cycle services from spreading.

There are good reasons for the international community to have tight control on nuclear fuel production and services. Countries that have mastered uranium enrichment and plutonium separation can be viewed as nuclear weapon *capable* states because they could develop nuclear weapons within a short time span if they chose to do so. According to the Director General of IAEA, Dr Mohamed ElBaradei (2009):

> This is too narrow a margin of security, in my opinion. These countries may have no intention of ever making nuclear weapons, but that can change quickly if their perception of the risks to their national security changes. And security perceptions, as we know, can change very rapidly.

Most countries that have nuclear fuel cycle capacity do not want to change the status quo and prefer to maintain their dominant positions in nuclear fuel services, even when more countries start building nuclear energy programmes. In general, the consensus is that the market approach – that is, countries that have the capacity to enrich uranium and reprocess spent fuel can lease or sell their fuel on the markets and the government of buyers will ensure the safeguard of the nuclear fuel in the country – would not work because nuclear fuel can easily be used for weapon programmes. It is the responsibility of the international community as a whole to ensure that the number of countries that possess enrichment facilities will not expand. The IAEA has been pushing for a multilateral mechanism to provide nuclear fuel cycle services, including enrichment, under the control of the IAEA in order to ensure the two objectives can be achieved simultaneously: nuclear energy expansion and stronger international regulation on non-proliferation.

In June 2004, the director general of IAEA appointed a group of experts from 27 countries to consider multilateral approaches to the civilian nuclear fuel cycle. Since then, various proposals have been put on the table (Table 2.8).

Table 2.8 Nuclear fuel supply proposals, 2003–07

Year	Agency	Proposal
2003	IAEA	Would establish internationally owned fuel cycle centres.
2004	USA	Would keep uranium enrichment and plutonium reprocessing in the hands of current technology holders, while providing fuel guarantees to those who abandon the option.
2005	IAEA	Explored a variety of options to address front end and back end problems and their attractiveness to different groups of states, and surveyed past proposals.
2005	Russia	Would establish international fuel cycle centres.
2006	USA	US Global Nuclear Energy Partnership originally proposed that certain recognised fuel cycle countries would ensure reliable supply to the rest of the world in return for commitments to renounce enrichment and reprocessing; it also proposed solutions for recycling of spent fuel and storage issues.
2006	USA, UK, Russia, France, Germany and the Netherlands	Six Country Concept would establish reliable access to nuclear fuel.

2006	Nuclear Threat Initiative	Promised $50 million for an international nuclear fuel bank under IAEA supervision provided another $100 million donated within two years and IAEA organises implementation.
2007	USA	Revised Global Nuclear Energy Partnership would promote an international nuclear fuel supply framework (without explicit renunciation of fuel technology) to reduce proliferation risk and a closed fuel cycle featuring recycling techniques that do not separate plutonium.

Source: Nikitin et al. (2009: 3).

One proposal is for the creation of regional co-production centres; for example, Brazil and Argentina, both of which have already had facilities, would expand their current facilities to provide nuclear fuels to the countries in the region that want to build NPPs. Such facilities would be overseen by the IAEA. This kind of arrangement is relatively easy for Latin American countries because, until now, no other countries have demanded to build uranium enrichment facilities. In Asia, such an arrangement seems almost impossible. Some experts discussed the possibility of the potential cooperation between Japan and South Korea in building a co-production facility. Both countries already have vast experience and a good record in operating their NPPs. Japan has developed full nuclear fuel cycle facilities while South Korea wanted to do so too. Even if the two countries cooperate, to whom are they going to supply nuclear fuel in the region? China has its own facilities and it does not seem feasible for China to give up or subject its facilities to cooperation with its eastern neighbours. Some countries in the Southeast Asian region, such as Malaysia and Indonesia, have made it clear that they do not intend to build nuclear fuel cycle facilities because even when they launch their nuclear energy programmes, the planned capacity for the next 10–20 years will not exceed 1,000 MWe each. Building nuclear fuel cycle facilities is not only costly but technically complicated. Some countries have reservations concerning the proposal because they want to maintain independence in fuel supplies. The issue is particularly difficult for countries in the South Asian sub-continent and the Middle East.

Russia has proposed a single international centre providing nuclear fuels, under the control of the IAEA. ‘To achieve this goal, a decision was taken to launch a pilot project to establish on the territory of the Russian Federation the International Uranium Enrichment Centre (IUEC) on the site of the Angarsk Elecyrolysis Chemical Complex [and] the main function of the IUEC is to provide IUEC participating organisations with guaranteed access to uranium enrichment capabilities’ (IAEA 2007a). This proposal had a wide range of opponents and limited support because it features a Russian facility and many countries do not want to see their nuclear fuel supplies lie in a country that they do not and cannot trust.

Germany has submitted a proposal for a multilateral approach to ensuring nuclear fuel supplies: the 'Multilateral Enrichment Sanctuary Project'. It called for the construction of an IAEA supervised, commercially administered uranium enrichment plant based on international property, which would be donated by a host country. The legal standing of the plant's territory would be akin to the status afforded to international organisations in host countries, whereby the IAEA would be given sovereign rights over the territory. The plant would be operated by a private firm, while the IAEA would retain control of a buffer fuel stock to be distributed on request by a state facing political or economic blockage of shipment. The extraterritorial status of the facility is at the centre of the proposal and the country that agrees to host the facility would have to be willing to cede administration and sovereign rights over a certain area to the IAEA. On this extraterritorial land, any country or firm could establish facilities, individually or collectively, that would be subject to the tight regulation of the IAEA, but would operate on a commercial basis. The German position is that this is the only way to break the monopoly of nuclear weapon states over enrichment and reprocessing.

Japan, while supporting the principles behind the Russian and German proposals for a multilateral approach to nuclear fuel supplies, submitted a very different proposal: they called for the establishment of a system called the 'IAEA Standby Arrangement System for the Assurance of Nuclear Fuel Supply'. According to this proposal, all countries would be allowed to have their own full nuclear cycle if they chose to do so, but they must register the uranium ore supply capacity, the uranium reserve capacity (including recovered uranium), the uranium conversion capacity, the uranium enrichment capacity and the fuel fabrication capacity with the IAEA. It would be 'a virtual arrangement, as participating states are supposed to continue to possess and control nuclear fuel supply capacity' (IAEA 2006).

The Nuclear Threat Initiative, a US-based non-governmental organisation (NGO), proposed the establishment of a nuclear fuel bank in a location to be designated by the IAEA, and called for the IAEA and its member states to administer a stockpile of low-enriched uranium (LEU) that would be available on a non-discriminatory, non-political basis to states that meet non-proliferation requirements. Until late 2008, US$100 million was donated for the plan – US$50 million from US investor and philanthropist Warren Buffett and US$50 million allocated by the US Congress. The American government has also adopted a bilateral approach, guaranteeing nuclear fuel supplies if countries agree not to establish a full nuclear fuel cycle.

Key issues that emerged in the debate over a multilateral approach to nuclear fuel services do not seem to affect countries that have already had the facilities to enrich uranium or even to separate plutonium. Rather, they concern countries that are planning to build a nuclear energy programme. How are they planning to obtain nuclear fuels for their power plants? All countries agree on 'the right of every country to decide its own energy mix', including nuclear energy, and 'the inalienable right of every country to the peaceful use of nuclear energy'. The question is how to respect these rights while minimising possible proliferation risks emanating from the predicted wider use of nuclear power for civil purposes.

Public acceptance

Each method of producing electricity has its drawbacks and its own explicit and implicit environmental and health impacts. Of all the energy sources, nuclear is the most subject to polemics because of the way it is presented by the mass media, politicians and the nuclear community itself. The controversy over and opposition to nuclear energy have a great deal to do with its history: nuclear science was conceived with a military application and anti-nuclear discourse takes good advantage of this by playing on the public perception that nuclear technology is nothing more than a system for producing lethal weapons. Yet history alone cannot explain the concerns and fears of the public. For example, Japan is the only country that has suffered from the military use of nuclear science and technology, but it is a country that holds about 13 per cent of the world's total nuclear power generation capacity and its NPPs supply about 27 per cent of its total electricity consumption.

At the national level, the argument for and against nuclear energy is closely bound to national politics, national security, availability of alternative energy sources and environmental pollution. Where traditional forms of energy (oil, gas, coal and hydropower) are limited, or environmental pollution is a serious problem as a result of fossil fuels consumption, the nuclear option often seems to be viewed more favourably, as in the case of France, Japan and China. In countries with abundant energy resources, such as Australia and Germany, political or emotional debates can overshadow the analysis of nuclear energy. Within a given country, at the regional level, the line of debate is less clear. Debates are often tied to local economic conditions, employment opportunities, social mix and so on (NEA 2002). In some countries, the nuclear debate can be politicised in national politics while in others it is very much a local issue. In many countries 'even if there is a majority in support of the technology or business operation in a general sense at the national level, this does not guarantee support at the local level on a local issue of individual nuclear facility siting or operation' (Nagano 2008: 304).

The main generic concerns of the public about nuclear energy are familiar ones, including the safety of NPPs, radioactive waste management and disposal, and non-proliferation issues. The secrecy that is often involved in decision making on nuclear-related issues, for peaceful or military use, can aggravate public concern rather than contribute to a better understanding of the nuclear option.

Public concerns on the safety of NPPs focus on two main issues: the technical problems that can lead to disastrous accidents as seen at Chernobyl and Three Mile Island, and the potential for terrorist attacks on NPPs, which can be easy targets. There is a remarkable disparity in the fears over operational safety between developed and developing countries (Toth and Rogner 2008). Safety concerns appear to be the most strident in Europe – under the long shadow of Chernobyl – in Japan because of recent incidents, but also in Latin America despite it having only a few operating reactors, and in the South Pacific (Australia and New Zealand), which has no nuclear facilities at all. In contrast, safety issues cause less anxiety in South and Southwest Asia, where almost 20 reactors operate in densely populated areas. In South Asia, the public is generally supportive of expanding the nuclear energy programme; in Southeast Asia, traditional opposition among politicians and the public is shifting slowly towards being more positive to nuclear energy development (Grover 2008, Sudarsono 2008).

In Japan, pre-construction has witnessed the most difficult predicament and most difficulties because of public resistance to having NPPs in their backyards (Lesbirel 1998, Nagano 2008). In South Korea and Taiwan, two apparently contradictory statements have been presented: those who know little about nuclear energy development in the country often argue that neither country could build a new NPP as they did in the 1980s under the military and authoritarian regime because the public would resist the new NPP project. At the same time, both countries have new projects under construction (six in South Korea and two in Taiwan) and the public does not seem to be opposed to these projects. In both South Korea and China, the argument presented by government that the nuclear energy programme will have a significant technological spill-over effect on the whole economy is, by and large, endorsed by the public (Yoo and Yoo 2009). The nuclear energy programme has broad support in China mainly because of the environmental problems the country is facing while increasing concerns were raised on the specific siting of several NPPs (Xu 2008).

Public fear of nuclear accidents is nonetheless real, even though there may be misinformation and misunderstanding of these accidents. For example, after the Chernobyl disaster, public opinion on nuclear energy was the main reason that many OECD countries halted, or decided to phase out, their nuclear energy programmes. To some scientists, however, 'there is a gulf between public perception of nuclear safety and the reality' (Baruch 2008: 115). According to their estimates, as the result of the Chernobyl accident, 28 people died from acute radioactive syndrome, 2 people died at Unit 5 from injuries related to radiation, 1 person died of coronary thrombosis, and 19 people died between 1987 and 2004 of various causes not definitely attributed to radiation exposure. According to others, the accident was a real disaster because it 'killed at least 4056 people and damaged almost $7 billion of property' (Sovacool 2008: 1806).

In the USA, which has the largest number of NPPs, 'while one can easily count scores of workers who have been killed in refinery, petrochemical plant and coal mining operations over the decades, not a single US nuclear worker has been killed in the workplace or in accidents relating to workplace conditions' (Herbst and Hopley 2007: 127).

Meanwhile, there has been a significant and fundamental change in the technology used in NPPs. The generation III reactors are efficient, with capacity factors exceeding 90 per cent, and have a high degree of passive safety based on the inherent principles of physics. The reactors in Chernobyl that caused the disaster used a graphite moderator and graphite to cool the system. Light water pressurised reactors, which account for more than two-thirds of the world's reactors, use ordinary water as a coolant and as a moderator to slow the neurons emitted by the core. 'There is a great difference between the two: water has a negative reactivity coefficient, while graphite-moderated reactors (no longer being produced) have the opposite effect that can "run away" and burn with disastrous results if the temperature in the reactor rises' (Baruch 2008: 115). Comparing the reactors used today against the type of reactor that was destroyed at Chernobyl in the Ukraine is like 'comparing the safety of a World War I biplane against a modern jetliner'. 'Nuclear power plants have better safety performance today than ever, and future generations of reactors will have design modifications that enhance safety even further' (Meserve 2004: 433).

This world of difference in technology used in NPPs is seldom recognised by anti-nuclear campaigners, who do not make any distinction between types of reactors. The fact that nuclear reactors can break down and have the capacity to harm people and their livelihoods can be much more readily embraced by the public than the complicated technical reality presented by scientists. Consequently, a simple equation is drawn by anti-nuclear campaigners: NPPs equal Chernobyl or Three Mile Island disasters. It is clear that the public needs to be better informed about the technology used in NPPs and the accidents and long-term impact of nuclear energy, especially in the context of other energy sources. Some observers have argued that the real obstacle to nuclear energy development, however, is not negative public attitudes but political opposition – that is, politicians tend to use nuclear issues for their own political gains.

According to the communication director of Foratom, the European atomic forum for nuclear energy in Europe:

- In Germany in the year 2000, 60 per cent believed that phase out is not realistic in the short term.

- In Sweden in the year 2000, 77 per cent opposed early closure of nuclear power plants.
- In Finland in the year 2000, more than 66 per cent believed nuclear was 'not risk-bearing'.
- In France in 2001, 67 per cent said that nuclear is important to the country's security of energy supply.
- In the Czech Republic in 2001, 58 per cent supported the completion of the Temelin nuclear power plant.
- In the USA in 2001, 68 per cent said that nuclear energy should play an important role in meeting future energy needs (http://www.iaea.org/worldatom/Meetings/2001/KDaifuku-Opening.pdf).

Of course, this is the research conducted by the nuclear industry, which stands to benefit from the results. The issue, however, is that there are differences between what is presented to the public by politicians and what the public understands about nuclear energy. For example, in Japan, even though about 70 per cent of people who were surveyed 'felt uneasy about nuclear energy due to the risk of incidents and some recent scandal', 'two thirds of the public considered nuclear power as a significant energy source for Japan's electricity supply' (NEA 2002: 114). In Finland, while nuclear power was considered to 'be contributing to economic and reliable energy supply as well as welfare and to the reduction of the greenhouse effect', about 70 per cent of people who were surveyed 'regarded nuclear power as a potentially dangerous and risky method of electricity generation'. There was similar contradictory public opinion in other OECD countries, as in the USA, 'there was nearly a consensus on keeping the existing nuclear power plants in operation and renewing the licences of those plants' and nearly three-quarters of those surveyed 'agreed to keep the option to build more nuclear energy plants in the future' (NEA 2002: 114). Yet, when asked whether they would support the construction of an NPP in their region, the 'not-in-my-backyard' principle remains strong in OECD countries, where increasingly 'nuclear power was considered a main source of energy that would make the greatest contribution to energy supply in the next 10 years' (NEA 2002: 112).

Some studies in Finland, Sweden and the UK have demonstrated that the better the public is informed, the less opposition they have to NPPs, and in many cases, the closer they are to an NPP site, the less opposition they have, again because they are better informed. Studies have also demonstrated that when energy resources are not accessible, or where there are frequent blackouts or brownouts, the public has much less resistance to nuclear energy than those who take reliable supply of electricity for granted or those in countries where natural energy endowment is high. When environmental pollution as the result of thermal power generation has an immediate impact on people's health and quality of life, the public weighs the benefit of nuclear energy above the problem of its long-term waste disposal.

'Public perception is also dependent on many factors specific to a given society such as the local energy supply position, national experience with nuclear power and national perceptions of environmental considerations' (IAEA 2008: 31). Recently, public acceptance of nuclear energy has improved greatly because of concerns regarding higher fossil fuel prices, supply security and climate change, and because of an improved nuclear safety record. Including nuclear power in the energy mix is seen as a safe option that can perform a crucial role in meeting energy needs. As studies have shown, more transparency and better access to information have encouraged public acceptance for nuclear power.

Waste management

Another factor 'shaping the public perception of nuclear energy is the risks associated with the interim storage of spent fuel and the long-term disposal of nuclear waste' (Toth 2008: 17). Radioactive waste is generated at each stage of the nuclear fuel cycle: uranium mining, uranium enrichment and fuel fabrication, NPP operation, reprocessing and decommissioning of NPPs. It may be low radioactive or high radioactive waste, both of which have to be carefully managed and accounted for because they are potentially hazardous to human health. Uranium mining and milling produce a large amount of tailings, containing 70 per cent of the radioactivity originally present in the ore. This is the issue Australia has been struggling with and currently, 'where possible, the tailings are covered by water to reduce the production of acid water [and] the water is treated until the permitted discharge quality is met. Where such treatment is not possible, the tailings are stabilised and covered with soil' (IAEA 2007c: 7).

The great majority of radioactivity produced during the nuclear fuel cycle is contained in the spent fuel. While the volume of radioactive waste is much less than that of many other kinds of hazardous chemo-toxic waste, it has some features which set it apart. Simply being in close proximity to radioactive waste can be hazardous and that is the reason radioactive wastes are generally managed by isolation. Another feature is that radiation contained in waste decays very slowly, from 300 years in low-level waste from uranium mining and milling to more than 10,000 years in intermediate-level waste from general operation and maintenance of nuclear facilities, and more than 100,000 years in high-level waste from the reprocessing of spent fuel. A positive aspect is that, compared with other classes of radioactive waste and with the waste production of other industrial sectors, spent fuel and high-level waste are generated in relatively small volumes and masses. Nonetheless, accumulation of radioactive material is a burden for human society both at present and in the future.

For now, both the IAEA and NEA are optimistic about waste management worldwide. The technology for disposal of short-lived low- and intermediate-level waste is well defined and developed, and 'most countries with major nuclear power programmes operate repositories for this kind of waste' (NEA 2008: 244). The spent fuel from nuclear reactors is generally stored in purpose-built storage facilities on sites close to reactors. Globally, there is sufficient storage capacity and 'a storage shortage is not expected globally, as measures can be undertaken to increase the capacity of current storage facilities or new storage projects may be launched' (NEA 2007, 2008: 247).

Presently, waste management is not a major obstacle for many Asian countries that wish to expand or develop their nuclear energy programmes, partly because they have not faced the issue to the same extent as countries that have already accumulated a large quantity of radioactive waste and are facing the issue of decommissioning. In many developing countries, such as China and India, the challenge posed by waste management (long-term potential environmental problems) seems to be overshadowed by the immediate threat of many environmental problems. They also depend on the human capacity to develop new technology to deal with these issues by, for example, developing closed fuel cycles with recycling transuranic elements extracting more usable materials from uranium and spent fuel.

A number of countries have had plans to build geological disposal facilities to be in operation within the next two or three decades. 'These repositories are generally designed to provide disposal capacity for all the high-level waste resulting both from historical nuclear power generation and from the lifetime operation of the existing and planned nuclear fleet' (NEA 2008: 256). Building such facilities may not be possible in many developing countries given their high population density and geological conditions. It is not a problem for the next two or three decades but an issue that needs to be discussed well before any nuclear energy programme is launched. Waste management may eventually become an international issue that requires multilateral cooperation. Proposals have been on the table for multilateral cooperation together with those on multilateral cooperation on fuel supplies.

Planning and regulation

As most Asian countries are preparing to expand or to build their nuclear energy programmes, how to deal with the challenges of each of the above-mentioned issues depends, by and large, on a government's role and capacity in planning and regulating the field. No expansion or development of nuclear energy programmes can take place without a well-developed long-term strategy.

With this in mind, the following questions are pertinent. What would be the optimal energy mix in a country given its natural resources endowment? What would be the favourable macroeconomic conditions for nuclear development? What would be the strategy for technology introduction and adaptation? How can plant safety and radioactive waste be managed? And how can public support be secured for nuclear energy development?

Investors will not be interested if the investment environment is unstable or the price system does not allow them to recover costs. Even if a country decides to build its nuclear energy programme by introducing turnkey reactors, it needs a local labour force that has the capacity to operate them. Public support is necessary and a better informed public is more receptive to nuclear energy, as has been demonstrated in many countries. In sum, governments have been deeply involved in the development of nuclear energy, and their capacity to make long-term plans, to create an amenable political and economic environment, and to establish sets of laws, rules and regulations varies greatly.

First, a well-developed long-term energy strategy is necessary. 'Energy policy and its implementation are still a core function of governments and their intervention in this regard is globally beneficial to society' (NEA 2004: 23). In deciding the country's energy mix, a government has to take into consideration population growth, economic development (e.g. how energy can promote development in order to achieve the MDG), electricity demand, natural resources endowments and the environmental consequences of each of the energy sources. For example, some Asian countries such as Japan and South Korea have limited energy resources; others may have abundant energy resources in aggregate terms but these may be limited on a per capita basis, such as in China and India.

When countries rely on coal to generate electricity, as is the case with China, Indonesia and India, climate change considerations may force them to re-evaluate their energy mix. In deciding the energy mix, a government has hard choices to make. What energy sources should be given priority in order to ensure secure and adequate supplies? When and how should a government intervene to ensure public goods can be delivered and the long-term interests of the country can be protected? When costs favour fossil fuels, which of these fuels can have detrimental environmental consequences? How can a government ensure measures, such as energy efficiency, renewable energy sources and carbon capture, are integrated in its policy on nuclear energy? Common to all of these issues is that there are difficult political decisions to be made. For example, when the coal industry is one of the oldest industries, employs a substantial number of people and has strong political clout, it is difficult for the government to decide to replace dirty coal-fired power plants with NPPs, which involve higher costs and risks.

Second, electricity sectors worldwide used to be vertically integrated and monopolistic. Since the 1990s, however, pressure to restructure electricity supply industries has led to the unbundling of its segments for those that can be open for competition (generation and retailing) and those that should be regulated (transmission and distribution). In many OECD countries the old regulated public utility no longer exists and the merchant investment framework has significantly increased the cost of capital faced by investors, which makes long lead time and capital-intensive generation technologies in the nuclear sector much less attractive (Joskow and Parsons 2009).

In countries such as France and South Korea, the vertically integrated structure of their electricity markets remains in favour of nuclear energy. Reforms in the electricity sector have also been adopted in some Asian countries. In China, for example, generation is mainly open for competition but not for transmission and distribution. In India, limited competition is allowed in generation while regulation has been put in place in most states for transmission and distribution. Many developing countries are still in the process of unbundling and restructuring their electricity sector and decisions made by governments will affect the scope and speed of their nuclear energy programmes.

Although the introduction of competition in electricity supply is relatively new, one effect of market liberalisation is to expose the cost of meeting public policy objectives; that is, the cost of supporting uneconomic domestic coal mining, or supporting domestic equipment supplies, is to be shifted from within the internal accounts of power generation companies to explicit, publicly accessible accounts, which are shouldered by investors rather than governments. With these changes, utilities undertake more risks in investing in nuclear energy industry. Governments meanwhile have to strengthen their regulatory capacity to ensure that the public interest is protected and the risks are better allocated to parties able to take action to mitigate them.

Ultimately, this restructure affects the cost of investment and the structure of power tariff setting. For economic and safety reasons, NPPs are usually operated as base-load, and they run full-time since capital charges apply whether a plant runs or not. Technically they are easier to run at a constant output. This means nuclear power can be economically competitive with existing utilities that operate thermal power plants, which may or may not want such competition. Given that there is a significant market concentration in the nuclear energy industry (in nuclear plant construction and nuclear fuel supplies), this oligopolistic market structure has the effect of maintaining prices at a relatively high level, which allows firms to earn above-market profits. This, in turn, encourages investment. It also calls for an active role for governments in developing countries to ensure that these oligopolies do not take advantage of less-developed local economies.

Third, since the safety of NPPs is the most important public concern, whether this concern is terrorist related or based on the possibility of technical failure, it is the government's responsibility to ensure design and operational principles, and sound engineering and technical standards are met. These are key factors for the survival of the nuclear industry. All OECD countries with nuclear energy programmes have licensing processes for plant construction and operations mandated by legislation. The licences are granted either by governments or by regulatory authorities that have a high degree of independence. All OECD countries also have environmental assessment processes to ensure that the impact of a new plant is acceptable, although this may not be the case in many developing countries. In several countries (such as in Bangladesh, Indonesia, Malaysia and Vietnam), before a nuclear energy programme is launched, a regulatory agency is created. Creating an independent regulatory agency does not guarantee an independent and effective regulation. Building up the government's regulatory capacity is a precondition for a successful nuclear energy programme and this takes time.

'Governments have a role in setting up public processes for the siting and approval of all nuclear installations' (NEA 2004: 90). Without a functional legal system and operational regulatory regime to ensure the quality and safety of NPPs, rushing into nuclear development in many developing countries may exacerbate the potential for corruption. Studies have long established that the larger the projects, the more opportunity there is for corruption unless a well-established institutional framework exists to deal with the problem. With an established and functional institutional framework, large projects can also be translated into jobs for local development.

Fourth, nuclear energy development needs a long-term plan because of its high demand in a country's human capital and basic research and development. 'Nuclear technology may be a component of a country's energy policy for reasons of diversity and security of supply, or because of its contribution to air quality and emissions reduction' (NEA 2004: 48). It is also an area where, by deciding the choice of nuclear technology, a government can generally foster and support research and development in their country. On issues of both technology selection and research and development, governments have an important role to play in providing financial resources to facilitate the process of training and research and development in their country.

Finally, nuclear security is one of the main platforms of the anti-nuclear argument because nuclear materials can easily be transported and NPPs are relatively easy targets for terrorists. 'There are security issues associated with each phase of the nuclear fuel cycle' (Lowry 2007: 146). This is the reason the international community has been calling for a multilateral approach on nuclear fuel supplies and tight national regulation on controls over the export of sensitive nuclear materials and technologies. It is a government's decision whether or not a country's nuclear energy programme would need a compatible nuclear fuel cycle or if they would purchase nuclear fuel from an international market. It is also a government's decision to participate in multilateral negotiations on nuclear fuel supplies under the auspices of the IAEA.

Conclusion

The growing energy demand in the twenty-first century is driven by rapidly increasing population growth, the desire to connect 1.4 billion people who do not have access to electricity and 2.4 billion who have no access to a modern energy system. Limited and rapidly depleting fossil fuel resources have brought nuclear energy to the fore, especially in Asia where continuing industrialisation and urbanisation are requiring a large-scale supply of base-load electricity. Nuclear power that generates almost no direct CO_2 emissions and relatively few from the nuclear fuel cycle as a whole is therefore seen by many as part of the solution to the problems of inadequate electricity supplies and threats of global warming and climate change. This being said, nuclear power is not the only option these Asian countries are pursuing. Countries like China and India are grabbing every opportunity and every alternative. Nuclear is one of the low-carbon energy sources being developed to supplement fossil fuels.

This attraction to nuclear energy is supported by the improved performance of the nuclear energy industry since the 1980s. With more than 13,000 reactor-years of experience, the safety record of NPPs matches the improvement in efficiency. For these reasons, developing countries are at the forefront in the development and expansion of nuclear energy programmes. Of course, there are major challenges ahead. They include safety, security, human and technological development, economic and political support. Different political systems will have different ways of dealing with these challenges, and building a government's capacity to plan and regulate nuclear energy development is a necessary precondition for its development.

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3 Nuclear Energy Development in China

Sang Dongli

History of nuclear energy policies

The beginning of nuclear power, 1978–95

The People's Republic of China is one of the few countries in the world that has a relatively complete nuclear industry. China embarked on nuclear power in the late 1970s, during which time the Chinese government adjusted the strategy on national defence construction and turned their position of combativeness to one of peaceful modernisation and construction. In this context, in March 1981 the State Council made a decision that the nuclear industry should transfer its work focus to the service of the national economy and to improving the lives of its citizens. This transformation of China's nuclear industry aimed at 'seeking to develop a diversified energy base' (Zhou 1987: 43).

China started its nuclear power construction in the 1980s, based on the principle of a combination of self-reliance and introduction of foreign technology and expertise. In accordance with the government's policy of developing nuclear power appropriately, China's nuclear programme proceeded methodically with the emphasis placed on selected projects (Zhou 1987: 44). The first nuclear power project at Qinshan, in Zhejiang province, was domestically designed and had a capacity of 300 MWe. It was constructed in March 1985 and was connected to the grid for electricity production on 15 December 1991. Thus, Qinshan nuclear power plant became an important milestone in China's peaceful use of nuclear power.

When economic reform was launched in late 1978, the Chinese government started preparations to construct a nuclear power plant (NPP) at Daya Bay, in Guangdong province, 50 kilometres from Hong Kong, as part of the initiative of opening up to the outside world. The project was approved in December 1982. It consisted of two imported turnkey pressurised water reactors (PWRs) with the capacity of 900 MWe each. The Guangdong Nuclear Power Joint Venture Co. with Hong Kong's China Light and Power Co. Ltd as a co-financer (25 per cent of initial investment) and buyer of electricity (purchasing 70 per cent of electricity from Daya Bay) was the first power joint venture in China. This joint venture then raised 90 per cent of the station's cost (US$3.6 billion) from concession loans and from international markets. The construction of the Daya Bay project started in 1987 and was completed in 1994.

The slow development of nuclear power, 1996–2005

The Chinese government put forward a strategy of 'moderately developing nuclear power' in the Ninth Five-Year Plan (1996–2000). Under this strategy, nuclear power would be developed through a centralised administration and with unified planning, and be in line with the energy and electricity development of the whole country. The coastal region of southeast China, which was short of energy resources, but had a much faster economic growth rate, suffered from persistent electricity shortages and it was the region where the first two nuclear power plants were built, even though the development was slow for political, economic and technical reasons.

During the Ninth Five-Year Plan period (1996–2000), the Chinese government decided to construct four NPPs – Qinshan Phase II, Lingao of Guangdong, Qinshan Phase III and Lianyungang – eight units with a total installed capacity of 6,600 MWe. The Tenth Five-Year Plan (2001–05) incorporated the construction of eight NPPs, although the timeline for contracts was extended, putting the last two into the Eleventh Plan. China currently has six NPPs with eleven reactor units in commercial operation, with a total installed capacity of 9,124 MWe, of which six units with a total capacity of 4,736 MWe went to commercial operation during the Ninth and Tenth Five-Year Plan period (Table 3.1).

In March 2005, Premier Wen Jiabao said at a meeting of the Standing Committee of the State Council that 'China needs to change its structure of its

Table 3.1 Nuclear power plants in operation in China

Name of NPP	Reactor type	Technology		Capacity (MW)	Construction commence	Commercial operation
		Type	Source			
Qinshan	PWR	CNP300	China	300	Mar 1985	Apr 1994
Qinshan Phase II	PWR	CNP650	China	650 × 2	Jun 1996	Apr 2002
Qinshan Phase III	PHWR	CANDU6	Canada	728 × 2	Jun 1998	Jul 2003
Daya Bay	PWR	M310	France	984 × 2	Aug 1987	May 1994
Lingao Phase I	PWR	CPR1000	China	990 × 2	May 1997	Jan 2003
Tianwan	PWR	AES-91	Russia	1060 × 2	Oct 1999	Aug 2007

Source: http://www.heneng.net.cn/?mod=npp.

electricity generation; expand its hydro capacity, optimise its thermal development, actively promote nuclear energy, appropriately develop gas-fired electricity and encourage renewable energy.' This idea of 'active' development of nuclear energy was incorporated into the Eleventh Five-Year Plan (2006–10).

The Eleventh Five-Year Plan stresses that China should focus on the construction of a 1 million kilowatt-class nuclear power plant. It should gradually develop its own PWR advanced design, and its capacity to manufacture, construct and operate large-scale nuclear power plants, expand uranium exploration and mining, and build up nuclear fuel cycle capability, especially the back-end capacity of reprocessing spent fuel. It also emphasised the importance of developing human capacity to meet the demand for rapid expansion of nuclear energy projects. Nuclear energy development, as an important part of China's energy strategy, has been included for the first time in the National Overall Planning of Electricity Development during the Eleventh Five-Year Plan period.

Following this, in October 2007 the National Development and Reform Commission (NDRC) put forward a detailed policy of actively pushing the development of nuclear power to meet China's growing electricity demand – the Medium to Long-Term Nuclear Energy Development Plan (2005–20). The plan emphasises that nuclear energy development is crucial for ensuring the country's energy security, mitigating climate change and assisting general technological development. It sets the general development guidelines, which include unifying, standardising and localising nuclear technology, developing China's own Generation III reactor technology, and improving efficiency and competitiveness in producing nuclear equipment. The plan highlights the importance of 'safety first and quality first' in building, operating and managing advanced NPPs in conforming to an international advanced level; and the importance of establishing safety standards and an effective regulatory system.

In 2007, the State Council further elaborated the Medium to Long-Term Nuclear Energy Development Plan by issuing a document, 'China's Energy Conditions and Policies'. The document stated that China would encourage foreign investment in the construction and operation of nuclear power stations in which it holds the dominant share; China would also continue to import advanced technology and equipment through international bidding; and the government would offer preferential investment and taxation policies for nuclear energy projects. China would also increase its investment in research and development and in higher education in nuclear science, nuclear engineering and their related subjects at key universities.

According to the Medium to Long-Term Nuclear Development Plan (2005–20), China would build a 40 GWe nuclear capacity or about 4 per cent of the total installed power generating capacity by 2020. This would mean an annual electricity production of 2,600–2,800 TWh. An additional nuclear

Table 3.2 Nuclear power construction projects schedule assumption (GWe)

	New projects	**Under construction**	**Carry-over for next five years**	**Total operation by the end of five years**
Before 2000	–	–	–	2.268
10th FYP 2001–05	3.46	4.68	5.58	6.948
11th FYP 2006–10	12.44	5.58	12.44	12.528
12th FYP 2011–15	20.00	12.44	20.00	24.968
13th FYP 2015–20	18.00	20.00	18.00	44.968

Source: NDRC (2007: 8).

power capacity of about 23 GWe will be added on the basis of the current capacity of 16.968 GWe in operation or under construction (Table 3.2). By 2020, about 18 GWe of capacity would be under construction. Moreover, between 2005–10, the compound annual growth rate of China's installed nuclear power capacity is expected to be maintained at 11.9 per cent, and this figure is expected to rise to 12.8 per cent during 2010–20. The strategic development target has been incorporated into the National Electricity Development Plan. To meet these goals, China needs to find several new sites for nuclear power plants, while the existing nuclear power sites will be fully utilised and extended by constructing more reactor units.

These policies have provided opportunities for investors, equipment manufacturers and research institutions in nuclear energy expansion in China. Many observers believe that the 'spring' of nuclear energy development has come in China. By the end of 2009, China hosted more NPPs under construction than any other country in the world (Table 3.3).

Major players

Central government

The decision-making process in China in general is known for its fragmentation and bureaucratic rivalry (Lieberthal and Oksenberg 1988). The same can be said for nuclear energy decision making. The central government seems to have principal control because all nuclear power projects have to be approved by the State Council. In practice, however, several government agencies are involved in decision making. Unlike most countries in the world, China does not have a single ministry in charge of energy-making policy. That responsibility is shared by several agencies: NDRC is responsible for the country's general macroeconomic planning and therefore energy development is part of this planning. The Ministry of Finance has some decision-making powers relating to certain financial rules and cost standards; and the State-Owned Assets Supervision and Administration Commission

Table 3.3 Nuclear power plants under construction in China

Name of NPP	Reactor type	Technology		Capacity (MWe)	Construction start	Expected commercial operation
		type	Source			
Qinshan Phase II #3 #4	PWR	CNP650	China	650 × 2	March 2006 April 2006	December 2010 December 2011
Lingao Phase II	PWR	CPR1000	China	1000 × 2	December 2005	2010–11
Hongyanhe I	PWR	CPR1000	China	1000 × 4	August 2007	2012
Ningde I	PWR	CPR1000	China	1000 × 4	February 2008	2013
Fuqing #1 #2	PWR	AdvancedM310	France	1000 × 2	November 2008 June 2009	
Yangjiang	PWR	CPR1000	China	1000 × 6	December 2008	May 2014
Fangjiashan #1 #2	PWR	CNP1000	China	1100 × 2	December 2008 July 2009	Dec. 2013 October 2014
China experimental fast reactor	Fast reactor		Russia	250 × 1	May 2008	June 2010
Sanmen #1 #2	PWR	AP1000	USA	1250 × 2	April 2009 December 2009	November 2013 September 2014
Taishan	PWR	EPR	France	1750 × 2	November 2009	2013
Haiyang	PWR	AP1000	USA	1250 × 2	September 2009	2014–15
Shidaowan	HTGR	HTGR	China	200 × 1	2009–10	2013–14

Source: http://www.heneng.net.cn/?mod=npp.

(SASAC) exercises a supervisory role over state-owned enterprises, in particular in appointing and supervising senior executives.

In 2005, when energy demand exceeded its supplies and electricity shortages enveloped China, the State Council created the National Energy Leading Group to centralise the decision-making authority and coordinate activities of all energy sub-sectors, including nuclear energy. This group was led by the Premier and was an initiative and a prerogative of the government. In the energy sector, even though all major players are state-owned corporations, they do not operate in the same way as old-style state-owned enterprises (SOEs). Their self-interest was the very reason for the need to create a centralised institution to coordinate policy making and their activities. In the end, the group failed to achieve a great deal because of the changed players. None of the ministries represented in the group could speak on behalf of energy sub-sectors or had direct jurisdiction over all the major energy SOEs.

The problems and the ineffectiveness of the National Energy Leading Group quickly became apparent. The central government held extensive consultations with energy SOEs, academics and think tanks, looking for suggestions of a new governance structure for energy sectors. In 2008, after nearly five years of intensive national debate, the National People's Congress suggested the creation of the National Energy Commission (NEC) – a senior level discussion and coordinating body put together by the State Council – and the National Energy Administration (NEA), in charge of managing the country's energy industries, formulating energy strategies, drafting energy plans and policies, negotiating with international energy agencies and approving foreign energy investment. NEA replaced the Energy Department of the NDRC and absorbed the nuclear power administration of the Commission of Science, Technology and Industry for National Defence (COSTIND), which was downgraded again to a department, and placed under the Ministry of Industry and Information Technology (MIIT). This is the first time that nuclear power has been brought under the umbrella of national energy policy making.

NEA is not a 'super' ministry of energy, as many recommended and expected it to be. It can be seen as a halfway house between a fully fledged ministry and a subordinate department of the NDRC. It is set at the vice-ministerial level, accountable to both the NDRC and the State Council. The head of NEA is also the deputy minister of the NDRC, but NEA did not sever its relationship with the NDRC. One of the uncertainties surrounding NEA's establishment was how much autonomy it would have from the NDRC on energy policy. Indeed, the line of accountabilities is not clear: would it report directly to the State Council and the Premier or would it be accountable to the NDRC? To what extent can it deal with other relevant ministries on an equal level since it was set below the ministerial level?

A year after its creation, the State Council announced the size of the organisation – it would employ 120 full-time staff. This is a minute number compared with energy ministries in other countries, such as the US Energy Department that has more than 10,000 employees in its headquarters.

The China Atomic Energy Agency (CAEA), created in 1984, used to be an independent agency, reporting to the State Council. Currently, it is integrated into the MIIT. To the outside world, the name CAEA is still used and represents China at the International Atomic Energy Agency (IAEA) and other related institutions and treaties, such as the Non-Proliferation Treaty and Nuclear Supply Group. Its director is also a deputy minister of MIIT, and heads the downgraded COSTIND, currently a department under MIIT. According to CAEA's website, its main functions include:

- Deliberating on, and drawing up policies and regulations on, peaceful uses of nuclear energy.
- Deliberating on, and drawing up development programming, planning and industrial standards for peaceful uses of nuclear energy.
- Organising argumentation and giving approval to China's major nuclear R&D projects; supervising and coordinating the implementation of the major nuclear R&D projects.
- Carrying out nuclear material control, nuclear export supervision and management.
- Dealing with the exchange and cooperation in governments and international organisations, and taking part in IAEA and its activities in the name of the Chinese government.
- Taking the lead in organising the State Committee of Nuclear Accident Coordination, deliberating on, and drawing up and implementing a national plan for nuclear accidents and emergencies.

It also states that its work includes nuclear safety, research and development, the application of nuclear technologies, nuclear energy development in China and activities with the IAEA. In practice, none of these functions or categories of work are taken on or carried out by the CAEA, except when representing China at the IAEA. The policy-making function is in the hands of the NEA; the technical licensing and technical approval is under the National Nuclear Safety Administration (NNSA), which is independent, but is also under the auspices of the Ministry of Environmental Protection (MEP). The international cooperation falls under the jurisdiction of the Ministry of Commerce and the Ministry of Foreign Affairs.

NNSA was created as an independent agency in 1984 to ensure the safety of nuclear power plants in terms of construction and operation. It was accountable to the State Council until 2008, when it was placed under the MEP. All nuclear power plants need to obtain approval from both NNSA and MEP: NNSA issues licences and approves projects based on technical and safety standards, while MEP approves projects based on environmental assessment.

Nuclear safety was governed by the Environmental Protection Law of 1989, the Environmental Impact Assessment Law of 2002 and the Radioactive Pollution Prevention Law of 2003. This legislation, particularly the Environmental Impact Assessment Law of 2002, attaches importance to precautionary measures and public participation in the environmental impact assessment of relative plans and construction projects. According to the Environmental Impact Assessment of 2002, nuclear enterprises, experts and the public are encouraged to participate in assessing the environmental impacts of nuclear development (Article 5). The document outlines the importance of building the basic databases for assessing environmental impacts and the system of indicators for appraisal, and sharing the information about environmental impacts so as to make the environmental impact appraisals more scientific (Article 6); strengthening the institution to seek input from relevant entities, experts and the public on reporting the environmental impacts by organising public hearings and community meetings (Articles 11 and 21).

The Radioactive Pollution Prevention Law of 2003 is the most important legal document regulating nuclear waste management. Currently, spent fuel from nuclear power plants is stored on site. The central government currently concentrates on building facilities to store low- and intermediate-level radioactive waste. Research is underway to construct facilities for deep geological disposal of high-level and transuranium radioactive waste. China has intensified its efforts in research on critical technologies, such as the decommissioning of nuclear facilities, spent fuel reprocessing, and radioactive waste treatment and disposal to reduce the volume of radioactive waste and make nuclear energy sustainable.

The nuclear and radiation safety project is one of the Key Environmental Protection Projects during the Eleventh Five-Year Plan period, according to the National Eleventh Five-Year Plan for Environmental Protection (2006–10). China will set up systems such as a nuclear equipment performance examination laboratory, radioactive substance identification laboratories, a radioactive waste safety management centre, an electromagnetic radiation monitoring laboratory, a national radiation environment monitoring network, and a national nuclear and radiation safety supervision management system. In response to emergencies such as a nuclear accident, China has established the National Nuclear Emergency Response Coordination Committee that comprises 18 ministries and organisations. A national three-level nuclear accident emergency system is in place, with the central government, local government and utilities taking their respective responsibilities and making for a unified coordination.

China's ambitious plan for nuclear energy expansion has raised serious concerns about its regulatory system and regulatory capability. It needs to intensify its professional training to build a team of qualified regulators. Currently, that different models of reactors – French, Canadian, American and Chinese – are all used does not make it easier to regulate the industry. The call for standardisation and localisation of technology is made by experts in the industry and by international experts.

State-owned companies

For the past three decades, only two enterprises, which are state owned, have been allowed to invest, construct and operate nuclear power plants: China National Nuclear Power Corporation (CNNC) and China Guangdong Nuclear Power Holding Co. Ltd (CGNPC). China Nuclear Engineering Corporation (CNEC) was split from the CNNC in 1998 and is the only company that can construct nuclear power plants.

CNNC originated from the Ministry of Nuclear Industry and has evolved into a conglomerate with more than 100 subsidiary companies and a research institute. Until recently it controlled most of the business in the nuclear sector, including research and development (until the Shanghai Nuclear Energy Research and Design Institute was taken out to be the core of the State Nuclear Power Technology Corporation Ltd (SNPTC)), engineering design, uranium mining, fuel fabrication and fuel cycle services, and nuclear applications in medicine and agriculture. The China Institute of Atomic Energy (CIAE) is at the core of basic research in all aspects of nuclear sciences and engineering. It is responsible for researching and developing fast breed reactors and the back end of the nuclear fuel cycle. It owns and operates Qinshan I, II and III in Zhejiang and Tianwan in Jiangsu. Its other nuclear power stations under construction include Sanmen in Zhejiang (units of AP1000) and Fuqing in Fujian (two units of CNP1000).

The fastest growing nuclear operating company is the CGNPC. It was formally established in 1994 when Daya Bay was connected to the grid and it started its commercial operation with a registered capital of 10 billion yuan. CNNC owns 45 per cent of its share, Guangdong province owns 45 per cent and China Power Investment Corporation (CPI) has the rest, which used to be in the hands of the Ministry of Electric Power. It is, however, very much a product of the Guangdong government. The nuclear operating company started with nothing except sheer determination. It borrowed to build its first nuclear power station, sold its electricity to Hong Kong, paid back its borrowing and has built huge assets for further expansion. By 2007, it had a total nuclear capacity of 4 GWe, almost half of the country's total. It had total assets of 60 billion yuan compared with initial total assets of 3.24 billion yuan in 1994. In 2007, its total profit rose to 3 billion yuan and became the envy of the nation. It was so successful that several banks were lobbying to provide a line of credit for its expansion and CGNPC started issuing corporate bonds. In 2007, the State Council approved an experiment in Guangdong to build a 10 billion yuan fund for future nuclear energy development.

CGNPC now owns and operates Daya Bay and Lingao, and Lingdong (2 × 1000), Yangjiang (2 × 1000) and Taishan (2 × 1700) in Guangdong, Hongyanhe (4 × 1000) in Liaoning, and Ningde (2 × 1000) in Fujian is under construction. Construction of its project in Guangxi (Fangchenggang 6 × 1000) is about to commence. CGNPC has also expanded to other parts of the country. It signed an agreement with Hubei provincial government to prepare and develop nuclear power stations there, and it also signed a similar agreement with Anhui provincial government. It moved into Jiangsu where Tianwan is already in operation with CNNC as the owner and operator. In addition to nuclear energy, CGNPC has invested in wind, solar, hydro and other renewable energy projects. Finally, it is building a vertically integrated alliance system with its own subsidiaries as well as other major corporations in uranium trading, construction, research and development and personnel training. The simple fact that CGNPC made it onto the list of Chinese Backbone Corporations, but not the CNNC, says a great deal for its development and for its expansion strategy.

Five generating companies have tried to get their foot in the door of nuclear energy development because, in recent years, thermal generation has been a loss-making business and they face a great deal of uncertainty, mainly because of unreliable coal supplies and undependable rail transportation of coal. However, only CPI gained formal permission from the State Council in 2005 to enter the nuclear energy industry as a major shareholder. CPI was created in 1995 by the Ministry of Electric Power when the State Council decided to corporatise the business segments of the Ministry into the State Power Corporation of China (SPCC). CPI, whose assets were spin-offs from the Ministry, was to carry out several responsibilities, described by its first president as 'floating public power plants assets, issuing corporate bonds, establishing power development funds and channeling foreign investment for build-operate-transfer power projects'.

In 2002, in another major round of reform, China moved from a single, vertically integrated utility to two grid companies (a large one covering most of the country and a small one in the south) and a diverse set of generation companies (five large companies that were spin-offs from the original incumbent and a large number of other companies). The five companies are China Huaneng Power Group Corp., China Datang Corp., China Huadian Corp., China Guodian Corp. and CPI.

When the SPCC was unbundled in 2002, CPI, the smallest of the five companies, absorbed some non-productive segments of the SPCC. It also inherited the stakes in all nuclear power projects in China, originally held by the Ministry of Electric Power and then SPCC – 6 per cent of Qinshan II, 20 per cent of Qinshan III, 7.5 per cent of Daya Bay and 10 per cent of Lingao. It was not a surprise when, in November 2005, the National Energy Leading Group decided to grant CPI permission to invest in a nuclear power project as a controlling shareholder, partly because an expansion of a nuclear energy programme demanded more financial resources and partly because CPI had already controlled some portions of nuclear power projects. The other four power generation companies all have investment in some nuclear projects, either the ones under construction or those in a state of preparation. Zhai Ruoyu, a member of the National Committee of the Chinese People's Political Consultative Conference and the President of Datang Corporation, called on the Chinese government to grant licences for the other four power groups, except CPI, at 'the two meetings' of 2009. Huaneng Corporation has made substantive progress in its nuclear power project development (Huaneng 2008: 25).

The SNPTC was formally created by the State Council in 2007 as one of the elite SOEs in China. The initial investment for SNPTC came from the State Council (2.4 billion yuan, 60 per cent), and the large SOEs in the nuclear industry, CNNC, CGNPC, CPI and China National Technical Import and Export Corporation, with 10 per cent each. SNPTC is authorised by the State Council to sign contracts with foreign parties to receive the transferred Generation III nuclear power technology, and to carry out the relevant engineering design and project management. SNPTC is the key place where Generation III technology is introduced, adopted and absorbed. SNPTC is expected to develop a Chinese brand of nuclear reactors through the introduction of foreign technology. Its core is the Shanghai Nuclear Engineering Research and Design Institute, one of the oldest research institutes in China.

Even though CNNC and CGNPC each contributed 10 per cent of the initial investment, SNPTC joined the elite SOEs under the supervision of SASAC, on the same level as CNNC and CGNPC. It meant the old two-way competition between CNNC and CGNPC, which was slightly tilted towards CNNC, was replaced with a three-way competition – between Beijing, Shanghai and Guangzhou – for political and administrative supremacy over China's nuclear development. According to an official at the NDRC's Energy Research Institute, SNPTC was created to balance the influence of CNNC and CGNPC. If either CNNC or CGNPC gained control of AP1000, it would mean a monopoly. The industry needed competition and the power and influence of CNNC and CGNPC had to be balanced.

It is often argued in China that the current ownership arrangement in the nuclear industry is not conducive to competition because, for example, both CNNC and CPI are the stockholders of CGNPC. CNNC holds 45 per cent of the stocks in CGNPC while CPI owns a 10 per cent share of CGNPC. These ownership patterns inevitably lead to conflicting interests between competitors as well as contradictions in corporate governance. They could easily collude or place CGNPC in a disadvantaged position. A similar problem exists in SNTPC. CNNC, CPI, CGNPC and China National Technical Import and Export Corporation (CNTIC) each contributes 10 per cent of the SNTPC's total registered capital of 4 billion yuan. The ownership is particularly problematic because they are all owned by the state under the supervision of SASAC.

Another problem with China's state-owned nuclear companies is their low level of division of specialisation. Each nuclear company is pursuing the 'large and comprehensive' management mode with self-sufficiency. For example, initially CNNC was the only company that produced and distributed nuclear fuel services and now CGNPC is into uranium exploration and mining as well. CNNC, CGNPC and SNPTC all tried to develop their desired model of Chinese reactors – CNP600, CNP1000, CPR1000 and eventually the Generation III. No company concentrated its investment in its core business. Indeed, a situation has been created of duplicated capacity and construction and even excessive and disordered competition. As far as the equipment manufacturing companies are concerned, the three major power equipment groups – Haerbin Power Equipment Company Ltd, Shanghai Electric Group Co. Ltd and Dongfang Electric Corporation – have participated in the introduction and manufacture of nuclear power equipment for nearly 30 years. At present, these three companies are competing among themselves and with foreign companies; yet 'they are not interested in competition, but rather, in destroying their competitors (if the situation threatens the rent they can extract) or else in colluding' (IEA 2006: 77).

Another main obstacle facing all nuclear corporations is the short supply of qualified professionals. China has developed its own management system and cultivated a group of talented professionals with great ability to design and build equipment independently. All of this experience and technological progress has formed a good basis for faster development of China's nuclear power industry in the future. However, the current manpower is far from adequate to meet the needs of the unprecedented development of the nuclear power industry in China. For example, 5,600 new professionals are needed for CPI alone, which has less than 1,000 staff at present. According to CGNPC, to expand nuclear generation capacity as it planned, it would need to hire more than 13,500 engineers, technicians and operators for their existing and future nuclear plants. 'While 360,000 Chinese scientists and engineers graduate each year, few of them are trained in nuclear engineering disciplines' (Kadak 2008). It would take nearly 30 years for the current level of enrolment to produce this many skilled workers. Highly skilled and innovation-oriented technicians and technical workers are in short supply in industries, which is a serious concern for the industry and Chinese leaders (Ding 2008: 17).

Local governments

Many provincial and local governments, including some inland provinces, have shown a strong desire to develop nuclear power plants in their regions and launched early-stage site selection one after the other during the Eleventh Five-Year Plan period, with and without permission from the central government. This enthusiasm is partly the result of electricity shortages over several years and partly the result of relaxed investment regulations. But more importantly, it is because large projects tend to bring in investment, jobs and even opportunities for corruption (Table 3.4).

In a sense, nuclear energy development in China seems to follow a trend of 'blossoming everywhere'. The nuclear power projects under preparation for construction in some interior provinces include Hunan, Hubei, Jiangxi, Chongqing, Sichuan, Anhui, Henan and Jilin, all of which are at different stages of preparation. This new interest in nuclear projects has raised several concerns: (a) whether there is sufficient capital investment from nuclear corporations and local government and what kinds of economic risks are

Table 3.4 Nuclear power projects under early-stage preparations to construct in China

NPP		Reactor type	Technology		Nominal capacity (MWe)
Site	**Name**		**Type**	**Source**	
Hunan	Taohuajiang NPP	PWR	M310	France	1000 × 4
	Xiaomoshan NPP	PWR	AP1000	USA	1250 × 6
Hubei	Dafan NPP	PWR	Undetermined		4
Jiangxi	Pengze NPP	PWR	AP1000	USA	1250 × 4
Hainan	Changjiang NPP	PWR	CNP650	China	650 × 4
Guangdong	Lufeng Phase I	PWR	CPR1000	China	1080 × 4
	Haifeng NPP	PWR	Undetermined		1000 × 8
	Jieyang NPP	PWR	AP1000	USA	1000 × 6
	Shaoguan NPP	PWR	Undetermined		1250 × 4
Guangxi	Fangchenggang	PWR	CPR1000	China	1000 × 6
Liaoning	Xudapu NPP	PWR	Undetermined		1000 × 6
	Donggang NPP	PWR	Undetermined		1000 × 4
Chongqing	Fuling NPP	PWR	AP1000	USA	1250 × 4
Sichuan	Sanba NPP	PWR	Undetermined		1000 × 4
Zhejiang	Longyou NPP	PWR	Undetermined		1000 × 4
Fujian	Zhangzhou NPP	PWR	AP1000	USA	1250 × 6
	Sanming NPP	PWR	Generation-II plus	China	1000 × 4
Anhui	Wuhu NPP	PWR	Undetermined		1000 × 4
	Jiyang NPP	PWR	Undetermined		1000 × 4
Henan	Nanyang NPP	PWR	Undetermined		1000 × 6
Jilin	Jingyu NPP	PWR	AP1000	USA	1250 × 4

Source: http://www.heneng.net.cn.

involved; (b) whether China has already developed technology to build nuclear power plants in highly populated inland provinces where water shortage is always a concern; (c) whether the intensive investment in nuclear power projects would trigger inflation; (d) whether the industry has the capacity to expand nuclear programmes so widely; and (e) whether the country has the capacity to regulate the industry to ensure its safe development and operation.

The main interests for nuclear energy development

Why do China's policy makers support the development of nuclear energy? The answer may be found in China's twin challenges of ensuring electricity supply security and tackling environmental problems, including climate change. China's current energy strategy strives to build a stable, economical, clean and safe energy supply system, so as to support the sustained economic and social development with sustained energy development (SCIO 2007: 11).

As the most populated and fastest growing developing country in the world, China's total electricity consumption has increased rapidly since the late 1970s and will continue to grow steadily over the coming decades along with the rapid development of its economy, industrialisation, urbanisation and the substantial improvement in quality of life. Currently, China is the world's second-largest energy producer and consumer, although average energy consumption per capita still remains at a relatively low level compared with other developed countries.

China's electricity development in the past 30 years is recognised by the World Bank and other institutions as one of the main reasons for its poverty alleviation. During the same period, about 400 million people were connected to electricity and electricity consumption per capita rose from 260 kWh in 1978 to 2,328 kWh in 2007. It rose at an even faster speed in the 2000s, while it was catching up with the world average, but still fell far behind the average among OECD countries (Table 3.5).

Table 3.5 Electricity consumption per capita in China, OECD and worldwide, 2003–07 (kWh)

	2003	**2004**	**2005**	**2006**	**2007**
World average	2,429	2,516	2,596	2,659	2,752
OECD average	8,033	8,204	8,365	8,381	8,477
China	1,379	1,585	1,781	2,040	2,328
China as % of world	56.8	63.0	68.6	76.7	84.6
China as % of OECD	17.2	19.3	21.3	24.3	27.5

Source: IEA (2005–09).

Table 3.6 Investment in the electricity industry, 2002–07

	2002	2003	2004	2005	2006	2007
Annual GDP growth rate (%)	9.1	10	10.1	10.4	11.1	11.4
Annual growth rate in capital investment in electricity (%)	16.9	27.7	26.6	33.7	23.9	24.8
Annual growth rate of total installed generation capacity (%)	5.34	9.77	13.03	16.91	20.27	18.5
Annual growth rate of electricity generation (%)	12.26	16.77	14.66	12.89	15.30	14.84

Source: Minxuan (2008: 217–227).

After 2002, five generation companies invested heavily in expanding the installed generation capacity. Investment in power generation capacity much exceeded the general economic growth (Table 3.6).

Despite this rapid expansion of electricity capacity and production, power shortages were felt in most provinces. With continuing industrialisation and urbanisation, the Chinese government predicted that energy demand would double from the 2005 level by 2020, as would the total generation capacity, which would reach 1,500 GW by then. This has put great pressure on resources, especially coal, which has been meeting more than two-thirds of the total energy demand in China. In the past 25 years, more than two-thirds of the newly added generation capacity is fuelled by coal. At the end of 2008, more than 112 GW coal-fired generation capacity was under construction in China (IEA 2009), twice the existing generating capacity in all of Australia. Consequently demands for coal will continue to rise.

Coal production has increased in China. In 2006, China's coal output rose by 8.1 per cent to 2.3 billion tonnes, which is more than 45 per cent of the world's total production of hard coal. China has less than 14 per cent of the world's total coal reserves and its coal production in the past several years has accounted for 40–46 per cent of the world's total output. It is no surprise that coal mines have started to excavate much deeper into the ground and concerns about imminent depletion are growing as China has turned from one of the largest coal exporting countries to a coal importer, mainly from Indonesia, Vietnam and Australia (Mowli 1996; Herberg 2004; Schalizi 2006; Tang 2006).

Coal has not come cheap as the main fuel for power generation because it is predominantly located in the west and northwest regions of China and transporting coal to the load-centres along the coastal regions accounts for more than 50 per cent of the country's rail capacity. Heavy reliance on coal has had serious environmental consequences in China. 'Burning coal contributes to 90% of the national total sulphur dioxide (SO_2) emissions, about 70% of the national total dust, nitrogen oxide (NO_x) emissions and carbon dioxide (CO_2) emissions' (Zhang 2007: 3547). In 2006, China produced 2.31 million tonnes of sulphur dioxide, a 30 per cent increase in five years. China is now the world's largest emitter of SO_2 and the second largest of CO_2. Environmental pollution has been a major factor impeding sustainable economic and social development. According to the State Environmental Protection Agency, more than 70 per cent of the country's river systems are badly polluted, more than 300 million people do not have access to clean water and more than 400 million people in urban areas do not have clean air. China has 16 of the most polluted cities on the planet, and pollution in the air is claimed to cause the deaths of 400,000 people every 12 months. For China's neighbours, the problem is acutely visible, whether the pollution is wind-borne or in the river systems.

The economic costs of environmental pollution are high. According to the World Bank, the associated costs reached 8 per cent of GDP in China even a decade ago (World Bank 1997, 2007). The political costs are even higher. The devastating impact on the environment has become the focus of a growing number of local protests by disgruntled citizens. In 2005 alone, more than 50,000 disputes on violation of environmental regulations were reported to different levels of government. In the past two decades, the government has made a series of efforts to clean up the environment by closing down energy-intensive industries, small-sized steel mills, cement plants, small-size power plants and coal mines. It has not been successful, partly because there is still a demand for these companies' products, but mainly because these small-scale operations tend to be located in poor regions where the local economy depends on them. Instead of spending money and political capital on closing down these industries, the government would rather show the public that it was 'doing something' for the people and the environment. Building nuclear power plants is something that is visible and for which the government can claim credit.

The government has accepted the position that nuclear energy is 'the sole energy that can substitute fossil [fuels] in a centralised way and in a great amount with commercial availability and economic competitiveness' (Wang and Lu 2002: 8). Development of nuclear energy is seen as a way to materialise China's promise that 'future energy supply depends mainly on domestic resources' because uranium is considered as a quasi-domestic resource in China. Until recently, the price of natural uranium has been relatively low and the total cost of nuclear fuel services accounts for only a small proportion of the total cost of nuclear power. Moreover, it is possible to purchase a large quantity of natural uranium for strategic reserves from the international market when conditions are favourable. Nuclear energy is also clean, with few emissions of pollutants such as SO_2, NO_x and CO_2. With

Table 3.7 Producers of nuclear electricity

Country	Installed capacity		Production		% of nuclear in total domestic electricity production
	(GW)	% of world total	(TWh)	% of world total	
USA	106	28.5	837	30.8	19.4
France	63	16.9	440	16.2	77.9
Japan	49	13.2	264	9.7	23.5
Russia	22	5.9	160	5.9	15.8
Korea	18	4.8	143	5.3	33.6
Germany	20	5.4	141	5.2	22.3
Canada	13	3.5	93	3.4	14.6
Ukraine	13	3.5	93	3.4	47.2
Sweden	9	2.4	67	2.5	45.0
UK	11	3.0	63	2.3	16.1
Rest of the world	48	12.9	418	15.3	6.6
Total worldwide	372	100	2719	100	13.8

Source: IEA (2009: 17).

its financial, human and technical capacity, China should be able to expand nuclear energy capacity to deal with the challenges of energy security and climate change.

Despite the official policy of expanding nuclear energy capacity, its development takes time and resources. In 2007, China had only nine nuclear power reactors in operation with a total capacity of 8 GWe (1.1 per cent of the country's total installed generation capacity) and producing 62 TWh electricity (1.9 per cent of the country's total electricity generation) (IEA 2009: 647). China is far behind the world's leading nuclear power producers (Table 3.7).

In sum, even though China has decided to expand its nuclear energy capacity, it remains to be seen whether it can develop sufficiently and quickly enough to make a difference to energy supplies and to mitigate environmental pressures because nuclear development requires: (a) intensive capital investment, (b) high and sophisticated technology, (c) human capital and (d) operational and effective regulatory systems to ensure its safety.

Nuclear economics

Investment

According to the Medium to Long-Term Nuclear Development Plan, China would need an investment of 450 billion yuan to build 40 GWe nuclear generation capacity by 2020, of which 90 billion yuan would be the initial capital investment (NDRC 2007: 13). Other capital investment would be needed, for example, in uranium exploration, prospecting and mining. The government wants nuclear projects to be 'self-financed' by enterprises with commercial loans (NDRC 2007: 13–14) and these enterprises would be able to finance at least 20 per cent of the initial capital investment. However, it is not clear how this would work. Given that all nuclear enterprises are state owned and the loans would come from state-owned banks, on what terms and to what extent the government would be involved in allocating the resources to support nuclear energy expansion is uncertain. Another question is: which projects should have priority in terms of public financing?

Guangdong Daya Bay project was financed by the joint venture between Guangdong and Hong-Kong China Light. The loans were negotiated and secured by the central government. Once Daya Bay went into commercial operation, it was able to pay back the loans quickly by selling 70 per cent of the electricity to Hong Kong. This placed CGNPC in a healthy financial position when it decided to build another project in the late 1990s without financial assistance from other partners.

The rest of the nuclear power projects were all financed by the government, whether it was from the budget allocation, bank loans or international credits, which were all guaranteed by the central government. They were all able to 'make profits' because their initial loans were long term and concessional and, as SOEs, neither CNNC nor CGNPC had to pay the dividends to the 'owner' – the state represented by SASAC. The principle of constructing nuclear power plants with loans, and repaying loans with revenue from electricity sales did not really reflect the financial reality of the operation of all current nuclear power plants.

At present, CNNC, CGNPC and CPI are all securing cooperation with domestic banks. For example, CPI signed a Strategic Cooperation Agreement with the Industrial and Commercial Bank of China (ICBC) in Beijing on 24 June 2009. This is regarded as a milestone in cooperation between these parties. According to the agreement, ICBC would provide CPI with 80 billion yuan of credit and comprehensive services in cash management and financing, while CPI would give ICBC priority in financial cooperation on equal conditions. Soon after this agreement was signed, on 30 June 2009, CPI and ICBC signed a Syndicated Loans Agreement for CPI Haiyang NPP Phase I for a total of 36.289 billion yuan.

To make nuclear power a viable option, electricity prices must cover the cost of investment and operation, and provide an adequate margin of profit. Supporters of nuclear energy often argue that if the cost of transportation of fuel and environmental pollution is properly included in electricity pricing, coal-fired generation would not be as competitive as nuclear power. For example, a million kilowatt nuclear power unit needs nuclear fuel of 20–30 tonnes a year and its transportation would take no more than a few trucks.

Table 3.8 Comparative costs of nuclear and coal-fired power in Guangdong (yuan/kWh)

Cost account	**Nuclear power generation cost**		**Coal-fired power generation cost**	
	2004	**2008**	**2004**	**2008**
Fuel cost	0.030	0.057	0.140	0.287
Operation and maintenance cost	0.054	0.056	0.048	0.048
Depreciation expense	0.082	0.080	0.035	0.030
Financial cost	0.100	0.090	0.052	0.050
Spent fuel cost	0.031	0.028	–	–
Retirement cost	0.010	0.010	–	–
Desulphurisation cost	–	–	0.015	0.015
Decarburisation cost	–	–	0.045	0.045
Total	0.307	0.321	0.335	0.475

Source: Xiao (2008: 4).

In comparison, a thermal power unit with a million kilowatt capacity needs 2–3 million tonnes of coal a year and its transportation would take 100 train wagons every day (CNNC 2008: 22). If the decarburisation costs were included in the power generation costs in China, coal-fired power generation cost would be much higher than nuclear power generation cost (Table 3.8).

Currently, the average price of nuclear power in Guangdong Province is 0.415 yuan per kWh, and the price in Zhejiang Province is 0.426 yuan per kWh. Excluding Qinshan NPP, the nuclear power price from the other four nuclear power plants in Guangdong Province and Zhejiang Province is lower than the average on-grid price in the same power network (Table 3.9).

Preferential tax policies

The nuclear power industry requires a huge initial investment, and preferential tax policies are often regarded as an important and effective way to promote nuclear energy development. The current preferential tax and investment policies may be divided into two categories: one for nuclear power generation enterprises and the other for non-generation enterprises.

As for the former, the Ministry of Finance and the State Taxation Administration jointly promulgated the 'Notice on Tax Policy Issue in Relation to the Guangdong Daya Bay Nuclear Station' as early as 1998, which aimed to extend the favourable taxation terms to Guangdong Daya Bay Nuclear Station. In April 2008, the Ministry of Finance and the State Taxation Administration again jointly replaced the old policy with a 'Notice in Regard to

Table 3.9 Comparative nuclear power tariffs in the same grid (yuan/kWh)

	Average on-grid price	**Coal desulphurisation benchmark price**	**Nuclear power price**			
			Price		**Difference from on-grid price**	**Difference from coal benchmark price**
Guangdong	0.485	0.4532	Average	0.415	−0.070	−0.0382
			Daya Bay	0.414	−0.071	−0.0392
			Lingao	0.429	−0.056	−0.0242
Zhejiang	0441	0.4195	Average	0.426	−0.015	+0.0065
			Qinshan I	0.420	−0.021	+0.0005
			Qinshan II	0.393	−0.048	−0.0265
			Qinshan III	0.464	+0.023	+0.0445

Source: Shujie et al. (2006).

Tax Policy for the Nuclear Power Industry'. According to this document, for those nuclear power plants that commenced commercial operation within the past 15 years, there would be an upfront levy of value-added tax followed by subsequent tax refunds, with a gradually decreasing refund rate in three phases. Such value-added tax refunds should be calculated based on the nuclear power generation enterprises' electricity production and sales at the level of their generating units, and be exempt from corporate income tax. The specific refund rates are as follows:

- The refund rate is 75 per cent of the tax paid for those going on operation within the past five years.
- The refund rate would be 70 per cent for those going on operation within the past 6–10 years.
- For those starting their commercial operation production within the past 11–15 years, the refund rate would be 55 per cent.
- For those that have been in commercial operation production for more than 15 years, there would be no upfront taxation/subsequent refunds value-added tax.

Daya Bay Nuclear Power Station and Guangdong Nuclear Power Plant Investment Co. Ltd would continue to enjoy special treatment until 31 December 2014, including:

- Electricity sales from the Daya Bay Nuclear Power Station to Guangdong Nuclear Power Plant Investment Co. Ltd would benefit from a full VAT exemption.

- Electricity sales by Guangdong Nuclear Power Investment Co. Ltd to Guangdong Power Grid Corporation would benefit from the upfront taxation/subsequent tax refund policy for VAT, and are exempt from city maintenance construction tax and additional fees for educational funds.
- Electricity sales from the Daya Bay Nuclear Power Station to Hong Kong Nuclear Power Plant Investment Co. Ltd, and electricity produced by the Daya Bay Nuclear Power Station that is resold by Guangdong Nuclear Power Plant Investment Co. Ltd to Hong Kong Nuclear Power Plant Investment Co. Ltd, would all be exempt from VAT.

The Medium to Long-Term Development Plan of Nuclear Power also provided some preferential tax and investment policies to the Supporting Projects of the State Nuclear Power Self-Reliance Programme approved by the State Council and domestic enterprises undertaking the task of equipment manufacture, involving import tariff policy and value-added tax policy.

The main debate on technology adoption

Nuclear technology application is one of the three pillars of China's nuclear industry. There has been an endless debate on technology adoption. For example, what would be the best way for China to develop its own nuclear technology – through imports or development of indigenous technology? To what extent should China import nuclear technology? How can China standardise and localise the imported technology?

All nuclear reactors in operation in China use Generation II technologies, comprising mainly PWRs, designed and made in France, Russia and the USA, but also including heavy water reactors developed in Canada. Five of these 11 reactors use domestic technologies – CNP300, CNP650 and CPR1000 – while the generation units each use French, Canadian and Russian technologies. As for the 24 nuclear power generations under construction, 20 units adopt China's technology and the rest use CPR1000, except for two units of Qinshan NPP Phase II Extension Project that use CNP650, two units of Fuqing NPP that use French technology M310 and two units of Sanmen NPP that use US technology AP1000 (see Table 3.3). Daya Bay NPP was a turnkey project of the French proven M310 reactor. Qinshan NPP Phase III, as a project of cooperation between China and Canada, is the first heavy water NPP within the territory of China. Tianwan NPP adopts a Russian ASE-91 unit (an advanced type), which has been improved based on the experience of design, construction and operation of WWER-1000/320 series units, and the upgraded technology of Western PWRs. Qinshan NPP is the first NPP that has been designed and constructed autonomously. Qinshan NPP Phase II, following the Qinshan NPP, is another NPP that is designed and constructed autonomously. Lingao NPP Phase II is a leading project under the national self-reliance programme of the industry, which adopted the CGNPC's own technological route-CPR1000.

The Chinese government clearly stresses the principle of 'cooperating with international partners with China playing the key role' to promote nuclear power construction and technology research. At an NEA work conference in 2009, Zhang Guobao, head of the NEA, said that the proportion of domestic technologies and equipment used in China's nuclear power projects should be required to reach a certain level, and China can fully rely on its own technologies to support nuclear power development in the next two or three decades. Nevertheless, he gave no details on what level would be appropriate, but he did emphasise that developing domestic technologies should be a 'significant factor' in the planning, appraisal and approval of nuclear power projects.

The key question regarding technology adoption is how to deal with the relationship between technology introduction and indigenous research and development (R&D). In early February 2009, the State Council unveiled a plan to support machinery manufacturing industries, and encourage the use of indigenously developed key technologies and equipment in major projects. China has developed the ability to self-design, construct and operate the million kilowatt-class PWR nuclear power plant based on 'self-reliance and appropriate introduction of foreign technologies'. For example, Qinshan Phase II has achieved a high self-reliance and localisation rate, and a much lower specific cost compared with those introduced from abroad during the same period. Both CPR1000 of CGNPC and CNP1000 of CNNC are the improved Chinese second-generation PWR technology. CPR1000 has proved to be safe and reliable by its good operating records in Lingao NPP and is approved for commercial use. Yet CPR1000 was a duplicate of the advanced model French M310, which is not an indigenously designed and developed model. CNP1000, owned by CNNC, has not been approved by the NNSA. The construction of the 65 MWe China Experimental Fast Reactor is moving smoothly, and the feasibility studies for the 200 MWe high-temperature gas-cooled reactor have been completed.

A Generation III model was introduced when China decided to import Westinghouse AP1000 in 2007 to be built in Zhejiang and Shandong. In late 2007, an advanced French model of reactor, EPR, was introduced to be built in Guangdong. The SNPTC was created just to adopt Generation III technology and standardise and localise it so that China would be able, one day, to design and build its own nuclear power plants.

Before it develops its ability to design, build and operate its own nuclear power reactors, China has had several models of nuclear reactors in operation and under construction. While multiple models of technologies are used, the cost of nuclear energy will remain high and it will be difficult to regulate within a set of well-developed rules.

Prospects for the development of nuclear power in the coming decade

In early 2009, Zhang Guobao, head of the NEA, proposed that China should 'vigorously develop nuclear power'. The Chinese government updated its target of nuclear energy expansion from 40 to 60–70 GWe with 30 GWe under construction by 2020. Even if this target is achieved by then, nuclear power will account for 2.7–4 per cent of the country's total generation capacity and produce 4.8–7.2 per cent of electricity in China. Some nuclear experts would like to see a much faster rate of development. For example, Wang Dazhong, a renowned professor at Tsinghua University, and his colleagues would like to see nuclear energy contribute to about 16 per cent of China's total electricity generation by 2035. This would be translated into about 180 GWe installed nuclear generation capacity (Zhang et al. 2009). It is difficult to see how the country could find the financial, technological, material and human resources to achieve this target so quickly.

Is nuclear energy indeed the future? It depends: IAEA, IEA and the Chinese government emphasise that nuclear power is efficient, reliable, clean, safe and large enough to be used as base-load, if not to solve then at least to alleviate pressures from the twin problems China and the world are facing – energy security and climate change. Others see the current move as mere 'nuclear amnesia' because nuclear power will never be able to meet the growing demand or cut carbon emissions sufficiently to make a dent in the two main problems. One way of describing it is: 'nuclear power alone won't get us to where we need to be, but we won't get there without it' (Abu-Khader 2009: 225).

The challenges China is facing are real: while coal currently provides about 70 per cent of China's energy, it is depleting quickly. With about 15 million people moving to urban areas each year for the next two decades, it remains to be seen how China can meet its rising energy demand and keep its GHG emissions under control. At current rates, even if China meets its nuclear target, it would only be able to meet 4 per cent of the country's electricity demand and its total carbon emission will rise by 72–80 per cent by 2020. Clearly, something has to be done. China is too large a country to find a single solution to the challenges. By moving towards nuclear along the coast, wind and solar in the west and interior, and improving energy efficiency in general, China might avoid energy and climate disasters in the future.

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4

The Indian Nuclear Energy Programme: the Quest for Independence

Lavina Lee

Introduction

Since independence in 1947, India's leaders have held a fascination for nuclear energy in both its benign and destructive forms. As such, in the present period we cannot speak of a 'nuclear renaissance', but rather of a period of heightened faith in nuclear energy as a solution to three main problems that have faced the Indian state for some time: the alleviation of mass poverty, sustaining high levels of economic development and providing military security against external threats. In recent times, the issues of sustainable development and climate change have been added to this mix. Central to understanding India's trajectory in the nuclear field is the need to ensure that any solution to these problems builds upon and maintains India's ability to act independently in the world – a desire that is often looked upon by the outside world as stubborn and counterproductive. Nuclear power has long been seen as a solution to India's need to bring its people out of poverty on its own terms by providing an indigenous and potentially limitless source of energy to sustain economic development, while propelling the modernisation of India's science and technology capacities essential to a state aspiring to be among the first rank of nations. Similarly, the pursuit of nuclear weapons was seen to allow India to maintain a policy of non-alignment during the Cold War years, to provide a deterrent against attack by its neighbours China and Pakistan, and to sustain India's self-perception as a state with sufficient size and strength to be taken seriously as a Great Power. All of these considerations remain salient today.

This chapter seeks to explain why India sought to initiate and develop a nuclear energy programme and the challenges that it faces in expanding that programme into the future. To do so the chapter traces the historical development of the nuclear energy programme from the time of independence to the present day, analysing the political imperatives that resulted in India moving from a strictly civil programme to a military one. While the emphasis is on the trajectory of the nuclear energy programme, it is impossible to separate this from the effects of the comprehensive nuclear technology denial regime that was applied as a consequence of India's first nuclear test in 1974. Despite this regime, India managed to develop a truly indigenous nuclear energy capacity and has made progress on its long held goal of establishing a fast breeder programme. The final section of the chapter deals with the momentous shift in US–India relations during the term of the Bush Administration that resulted in the successful removal of the majority of international impediments to full civil nuclear cooperation with India in November 2008. We will assess the reasons for the fraught negotiations over the deal within the USA, India and the Nuclear Suppliers Group (NSG), the feared effects of the deal on the non-proliferation regime, the prospects for expansion of the energy programme and finally the possible climate mitigation effects of the deal.

The beginning

India's post-independence leaders were, from the outset, profoundly affected by the US demonstration of the power of atomic weapons in Japan in 1945, which 'reinforce[ed] the power of science for state ends, and India's own shortcomings in this regard' (Abraham 1998: 49). In November of that year, the future Prime Minister of India, Jawaharlal Nehru, commented upon the dual nature of nuclear energy as a technological leap with the capacity to 'either destroy human civilisation, or take it up to unheard of levels' (Bhatia 1979: 71). In the 1948 Constituent Assembly debates on the potential role atomic energy could play for India, Nehru made strong attempts to downplay the use of nuclear energy for defence purposes, and instead argued that India should develop a nuclear programme of its own or else remain a 'backward country' that would be left behind in a new industrial age (Bhatia 1979: 84). Atomic science would provide the solution to the problem of development while also swelling the pride and confidence of the new nation: it could be a potent source for electricity supplies essential for economic growth as well as an instrument by which the scientific and technological prowess of the country's educated classes would be developed. As little as possible was said about the possibility that India would develop a nuclear weapons programme.

However, Cabinet documents have revealed that in private, defence was also part of the nuclear equation for Nehru. In 1946, for example, Nehru wrote to the Cabinet: 'Modern defence as well as modern industry require scientific research both on a broad scale and in highly specialised ways. If India has not got highly qualified scientists and up-to-date scientific institutions in large numbers, it must remain a weak country incapable of playing a primary part in war' (quoted in Abraham 1998: 49). Similarly, in

1948 addressing the Constituent Assembly, he reluctantly acknowledged the possibility that India might in the future be forced to 'weaponise':

> Of course if we are compelled to use [atomic energy] for other purposes, possibly no pious sentiments of any of us will stop the nation from using it that way. But I do hope that our outlook in regard to this atomic energy is going to be a peaceful one . . . and not one of war and hatred.
>
> (quoted in Abraham 1998: 49)

This military element of the nuclear programme can go some way to explaining the secrecy and lack of outside scrutiny that the Indian Atomic Energy Commission (AEC) was to enjoy under the leadership of the nuclear physicist Dr Homi Bhabha. The AEC was established in 1948 by an Act of Parliament, the Atomic Energy Act, and was charged with directing the formulation of policy on nuclear matters under the oversight of the prime minister directly. In 1954, the Department of Atomic Energy (DAE) was created under the direction of the AEC as the governmental agency responsible for implementing its policies.

Over time, subsidiary organisations have been created to carry out this mission. They include the Nuclear Power Corporation of India Limited (NPCI), which is responsible for all aspects of the nuclear power programme, and BHAVINI which is responsible for the breeder reactor programme. The AEC's mission was to build up a strong indigenous skill base in physics, chemistry and metallurgy, to measure, locate and eventually harvest any atomic minerals, and to construct indigenously built and run nuclear reactors. Bhabha was appointed both as the chairman of the AEC and as the secretary of the DAE and had full control of the atomic programme (Kharnad 2008: 41). All activities relating to atomic science were to be controlled by the AEC and the DAE, both reporting directly to the prime minister, with strong sanctions being imposed to ensure secrecy around its activities. Funding for the agency was authorised directly by the prime minister with oversight only at the Cabinet level, which during the Nehru years was minimal (Abraham 1998: 61). The two-stage decision-making process between the prime minister and secretary for the DAE/chairman of the AEC ensured a high level of secrecy surrounding the atomic programme, while also facilitating quick decision making and a steady stream of funding, despite India's persistent economic problems (Kharnad 2008: 42).

While a stand-alone indigenous atomic energy capacity was the ultimate aim, India needed to seek foreign assistance from an early stage in relation to training, extraction of nuclear materials and the construction of nuclear power plants. Full use was made of the opportunities for international scientific knowledge sharing in civilian technologies under the 1953 US 'atoms for peace' programme, a programme that by today's standards fostered a remarkably open system of scientific exchange around the world (Kharnad 2008:

43). Indian scientists and technicians benefited greatly from overseas training at British, French and American national laboratories and universities. For example, 1,104 Indian scientists benefited from scientific exchanges at US facilities between 1955 and 1974, while 263 received training at Canadian installations before 1971 (Ramana 2007: 76). By 1957, the AEC was also offering its own graduate training programme, admitting 250 graduates 'for one year courses in physics, chemistry, metallurgy and engineering' (Bhatia 1979: 99).

The construction of nuclear industrial technology was similarly dependent upon external collaboration. In 1952, the extraction of large reserves of thorium from the monazite sands of South India was made possible via the construction of a factory in Alawaye, Travancore by the French company, Société de produits Chimique (Bhatia 1979: 87). British assistance in the form of enriched uranium fuel rods, technical plans, engineering drawings and data was invaluable in the construction by India of its first 1 MWe 'swimming pool' type research reactor, Apsara, in 1956 (Abraham 1998: 85). In 1955 the Canadian government agreed to build a 40 MWe NRX reactor or CIRUS experimental reactor at Trombay under the Colombo Plan, a scheme in which wealthy commonwealth countries provided developmental assistance to poorer members.

The Canadian offer was particularly generous as they agreed to absorb all foreign exchange costs and to waive a requirement for a clear safeguards agreement on the plutonium by-product of the reactor (Bhatia 1979: 91). In the following months, agreements were signed with the US Atomic Energy Commission for the sale of heavy water for the same reactor, and fuel elements were secured on loan from the UK Atomic Energy Commission. Finally, in 1960 India made its first power reactor purchases from Canada and the USA. The Canadians provided a 200 MWe heavy water moderated natural uranium CANDU reactor that could be fuelled by India's own natural resources, while two 200 MWe enriched uranium reactors were purchased from the American companies Westinghouse and General Electric to be built at Tarapur, a deal that included a US$80 million loan by the US government (*Nuclear India* 1970: 8–9; Abraham 1998: 94).

External scientific assistance to the Indian programme was largely forthcoming as a result of four factors. First, in the early years, the lure of accessing India's large thorium reserves – and preventing the USSR from doing so as well – provided a strong incentive for Western governments, concerned about shoring up supplies of nuclear materials, to collaborate in the development of the Indian nuclear programme (Abraham 1998: 78, 81). At the time, India was estimated to host 30–40 per cent of the world's thorium reserves (Kharnad 2008: 44). Second, initiatives such as the Colombo Plan formed part of the ongoing fight against the spread of communism. It was hoped that assisting a state such as India to develop economically, with its stated policy of neutrality and aspiring leadership of the developing world, would convince other Asian states to follow the capitalist model. The signing of a nuclear cooperation agreement between India and the Soviet Union in 1960 may well have raised fears about the alternatives (Bhatia 1979: 103).

Third, during this period nuclear states had begun to realise the potential export value of nuclear technology and materials and had begun actively to compete for markets among themselves. The first mover advantage was particularly acute given that the collaborative period of the Manhattan Project had given way to stand-alone national nuclear establishments, each becoming proficient in particular types of power generation such as enriched uranium reactors (the Soviet Union and the USA) or natural uranium reactors (France and Canada). Once a supplier was chosen, the buyer was essentially reliant upon the supplier for technical assistance and parts. The buyer, therefore, had an incentive to maintain positive relations with the seller into the future, providing a further means to bring India within its sphere of influence.

Fourth, the Indian government was acutely aware that external cooperation was contingent on India refraining from taking the military path and made consistent efforts to reassure foreign collaborators of their peaceful intentions. In the period between 1947 and 1957 various senior members of the government such as the defence minister and prime minister made repeated public statements about India's intentions to pursue nuclear technology as a potentially cheap source of electricity (Bhatia 1979: 89–91). In a speech to the Lok Sabha in May 1954, Nehru, for example, argued that 'the use of atomic energy for peaceful purposes is far more important for a country like India, whose power resources are limited, than for a country like France, an industrially advanced country' (Bhatia 1979: 94).

From this point forward the case for nuclear power was framed in terms of the projected gap between India's power needs for industrialisation and its natural resources in oil, coal and hydro-electricity. In 1955, Dr Bhabha argued that India would have no choice, in the decades to come, but to expend its foreign exchange reserves to import coal and oil to sustain a high rate of industrialisation. Nuclear power could not completely avoid this reality, but it could reduce its impact and become economically viable, particularly in parts of the country located furthest from known coal deposits (Bhatia 1979: 95, 101). To attain an element of energy security, Bhabha proposed the development of a three-stage nuclear programme, a plan that future leaders of the nuclear establishment have faithfully pursued. The core purpose of this plan was ultimately to set India on a path of energy self-sufficiency by overcoming the limitations of a nuclear programme based on uranium, a resource with which India is poorly endowed.

Under the three-stage plan, the existing uranium resources would be used to its maximum in the early stages while its vast reserves of thorium would be developed in the later stages, ideally to reduce its dependence on importing nuclear materials. In simple terms, India's three-stage nuclear programme aims towards a closed nuclear cycle in which fissile materials are reprocessed and recycled:

- Stage 1 – Pressurised heavy water reactors (PHWRs) use natural uranium as a fuel, and produce plutonium through reprocessing of the spent fuel.
- Stage 2 – Fast breeder reactors (FBR) use the reprocessed plutonium by-product and depleted uranium from Stage 1 to produce U233.
- Stage 3 – Advanced heavy water reactors (AHWRs) use the U233 produced in Stage 2 together with thorium to produce nuclear energy (Department of Atomic Energy n.d.b: 2; Gopalakrishnan 2002: 372; Glaser and Ramana 2007: 87).

Essential to this plan was the development of (FBRs), which at this time had not been perfected by any state. Given the development imperatives faced by India and the electricity demands this would entail, these plans were enthusiastically supported by the Indian Planning Commission's Third Five-Year Plan for 1961–66 (Bhatia 1979: 102).

The dark side of nuclear energy emerges

The October–November 1962 border war with China, in which the Indian Army was decisively defeated, placed great strain on the political consensus in the Indian Parliament over the exclusively peaceful nature of the nuclear programme. In the following year Nehru was initially successful in resisting the suggestion that India should develop a weapons programme for self-defence, largely because of the high costs involved, both economic and political. Such a move would also have contradicted India's position in international disarmament talks where it strongly called for the disarmament of the existing nuclear powers. Nehru held on to his public opposition to 'weaponising' the nuclear programme, stating on 25 March 1963 to the Lok Sabha: 'We have often said, from the very first day we started the reactor in Bombay, that we on no account would manufacture nuclear weapons . . . I hold to that' (quoted in Bhatia 1979: 121). Barely a year later, Nehru died and his successor, Lal Shastri, soon found it difficult to resist the rising calls within his own majority Congress Party for India to weaponise following China's explosion of its first nuclear device on 16 October of that year.

The Chinese test caused great turmoil within the ruling party in India. There was a fear that the Congress Party would be seen by the electorate as weak on national security and unable to face up to the reality of India's security position by clinging to utopian 'norms of peaceful co-existence and non-alignment' (Abraham 1998: 124). Nuclear weapons, it was argued, would enable India to regain some of its lost national confidence, and oppose Chinese aspirations to lead South Asia where India should be the only leader (Bhatia 1979: 110–111). While the Congress Party held a commanding majority with 356 out of 489 seats in the Lok Sabha, these apprehensions were vindicated with the loss of three by-elections in 1963.

Shastri, in November 1964, introduced a subtle document on the possible development of nuclear devices for so-called 'peaceful nuclear explosions' (PNE) for industrial uses such as 'tunnelling' and 'moving mountains', as envisaged under the American Plowshare PNE programme (Bhatia 1979: 120). In January 1965, at the annual conference of the Congress Party, while Shastri reiterated his support for a peaceful programme, he did not rule out a future change of stance (Bhatia 1979: 121).

Given the internal pressures on the Congress government to militarise the nuclear programme from 1962 onwards the question must be asked why India did not conduct a nuclear weapons test until 1974. The head of the AEC, Dr Homi Bhabha, had, after the Chinese test, boasted that India had the scientific capabilities to produce a bomb in 18 months at a relatively low cost (quoted in Bhatia 1979: 114). In terms of fissile material, by negotiating away the need for safeguards on the Canadian NRX CIRUS reactor, a source of weapons grade plutonium had also been available (Kharnad 2008: 47). By 1964, India had already built a reprocessing plant at Trombay to produce weapons grade nuclear materials (Kharnad 2008: 47). According to Abraham's calculations, India would have had enough plutonium to conduct a single explosive test by 1965 (Abraham 1998: 123). In addition, India was unable to negotiate protection from a joint USSR–US nuclear guarantee against a possible Chinese strike (Abraham 1998: 126). In these circumstances, China's thermonuclear 'booster' test in May 1996 would have provided an even greater incentive to militarise the nuclear programme.

A number of explanations have been put forward. First, any planning for a test would likely have been thrown into some disarray by the deaths of three important players: Nehru in 1964, and Bhabha and Lal Shastri in 1966. Second, it was at this time that India hit a financial crisis with rampant budget deficits and poor balance of trade numbers. Further, the country suffered crop failures in 1965 and 1966, requiring international emergency food aid and a devaluation of the rupee. Such a serious crisis inevitably refocused domestic attention on the role of nuclear energy for poverty alleviation and sustaining future economic growth rather than for purely defence-related issues. From a public perspective, the problem of food security and development was more pressing than the Chinese threat. Third, on the diplomatic front, the Indian leadership found it difficult to reconcile a nuclear weapons test with the state's carefully cultivated identity as a leader of the non-aligned movement and believer in peaceful coexistence, disarmament and non-proliferation. In the negotiations leading up to the 1970 Nuclear Non-Proliferation Treaty (NPT) India maintained the position that the greatest threat to peace came not from horizontal proliferation but from vertical proliferation. Any treaty that sought to restrain nuclear proliferation would also need to contain firm commitments by the nuclear weapons states to disarm or otherwise be discriminatory. Problematically for the negotiators, the Indian position was seen to have more weight given the perception that it could credibly claim to have eschewed becoming a weapons state itself, despite having the capacity and military imperative to do so after the China tests (Abraham 1998: 139).

Ultimately, India attempted to dispel accusations of hypocrisy in its stance on the necessity of nuclear disarmament by conducting the 1974 'peaceful' nuclear explosion with an externally estimated yield of 8 kilo-tonnes, close to the 10 kilo-tonnes yield of the Hiroshima bomb (Kharnad 2008: 54). While India might have demonstrated its capacity to build a working nuclear weapon for security purposes, few states believed that India had conducted a non-military test much like those undertaken by the USA under the Plowshare programme.

Self-sufficiency emerges by necessity

International reaction to the Indian Pokhran PNE was initially mixed, but soon set in motion the creation of an international technology denial regime at the instigation of the USA. Canada condemned the tests, ceased all assistance and parts supplies for the power reactors installed in Rajasthan and demanded that the International Atomic Energy Agency (IAEA) safeguards be placed on all Indian facilities. After India refused these demands all cooperation was terminated in 1976. To bolster the credibility of the newly created Nuclear Non-Proliferation Treaty (NPT), the USA was keen to take serious action internationally and domestically to defend the core bargain agreed to by the non-nuclear weapons states (NNWS). First, the 20 members of the Zanger Committee agreed upon a 'trigger list' of items that could not be exported unless the recipient state subjected their nuclear facilities to IAEA safeguards. Second, at the instigation of the USA, the NSG was created in 1975 as a voluntary association of nuclear suppliers who agreed to follow guidelines created by consensus to prevent the diversion of exported nuclear materials and technology to 'unsafeguarded nuclear fuel cycle or nuclear explosive activities' (IAEA 1978).

On the domestic front, US Congress passed the Nuclear Non-Proliferation Act 1978 to ensure that any future civilian cooperation with a NNWS could not be subverted for the production of nuclear weapons. Under this Act, nuclear exports to NNWS would require the application of full scope safeguards with termination of any agreement should that state conduct a weapons test or attempt to manufacture nuclear weapons (among other termination provisions). With India refusing to accept IAEA safeguards on the Tarapur reactors, the USA stopped its supply of low-enriched uranium (LEU) while General Electric was banned from providing India with nuclear spare parts or technical assistance (Gopalakrishnan 2002: 376). Initially, India was able to obtain alternative supplies of LEU from France until it too demanded full safeguards in 1995. This brought France into conformance with this requirement adopted by the NSG in 1992. China stepped in to supply nuclear fuel for these reactors until the 1998 weapons tests. From 2001 to 2004, and again after 2006, Russia provided India with nuclear fuels under the safety exception (Gopalakrishnan 2002: 377; Kerr 2009: 3).

The effective barring of exports of nuclear fuel, reactor components, equipment and dual use items to both the public and private sectors in India forced the Indian nuclear programme – military and civilian – to become a truly indigenous programme (Gonsalves 2009: 20–21). From 1987 onwards a public company was created by the DAE – the Nuclear Power Corporation of India – to be in charge of all aspects of nuclear energy development. The DAE was responsible for the construction and development of new reactor designs, utilising a growing pool of nuclear engineering and science graduates trained at the BARC Training School and, from the 1990s onwards, from Indian institutions of technology and universities. Most activities were directed towards the consolidation of Stage 1 of the nuclear plan – the expansion of the PHWR system – with all reactor components and subsystems having to be indigenously designed.

While self-reliance was the initial aim of the founders of the Indian nuclear programme, they were initially willing to work with other countries. The comprehensive international technology denial regime then created a siege mentality among the nuclear establishment. Self-reliance became a badge of honour, with members of this group taking on the role of guardians of India's ability to function independently and autonomously in both military and energy programmes. Yet, even though the indigenous civilian programme made significant strides, the ambitious plans for expanding nuclear power to meet the country's electricity needs have fallen far short because of international nuclear ostracism.

The nuclear weapons programme continued. India conducted a series of tests on 11 and 13 May 1998, which were followed by Pakistani nuclear tests on 28 May. Two major developments influenced the timing of these tests. First, there was a growing concern within the military establishment over the vulnerability of India to 'nuclear coercion' by China (Chellany 1998: 97) and its falling behind in its nuclear weapons programme. Taking the next step from fission to thermonuclear weaponry was argued to be necessary but it would require further testing. Second, following the conflicts between India and Pakistan in 1987 during the Brass Tacks military exercises and over the control of Kashmir (Khan 2009: 101–106) in 1990, the Indian government considered Pakistan as a serious immediate security threat.

From the Indian perspective, China had, and continues to have, a sizeable advantage in the size of its nuclear arsenal (estimated at around 400 warheads), a well-tested and proven thermonuclear weapons capability, and a superior capability to deliver these payloads to major Indian cities via intercontinental ballistic missiles with ranges of 8,000 to 12,000 kilometres. In addition, China remained Pakistan's key supplier of missile technology and nuclear assistance 'including the setting up of the Khushab plutonium-production reactor' (Chellany 1998: 97, 100). While the two countries had signed an agreement on 'The Maintenance of Peace and Tranquility Along the Line or Actual Control in the China–India Border Areas' in 1993, this agreement served only to de-escalate tensions over their disputed borders in Arunachal Pradesh and Aksai Chin, but did not resolve them. Further, in the years prior to 1998 Indian fears about the 'nuclearisation' of the Tibetan plateau were increased by intelligence showing Chinese modifications to airfields in Tibet to allow sorties on India to take place using Sukhoi aircraft (Synnott 1999: 15–16).

The impetus to test was also related to the opening for signature of the Comprehensive Test Ban Treaty (CTBT) in 1996 (Preparatory Commission 2010). The Indian leadership understood that it would come under increasing pressure to sign up and therefore the window of opportunity to close the nuclear gap with China would irretrievably disappear unless further testing was conducted (Karnad 2008: 64). On the domestic front, the ruling Bharatiya Janata Party (BJP) sought to use the nuclear issue to shore up support to hold this coalition government together (Synnott 1999: 18). The centrality of the nuclear programme for India's military and energy security was one issue on which all coalition members agreed. Apart from the security-based interests in testing, nuclear weapons were seen as a symbol of prestige, great power status and a guarantor of independent foreign policy action. These sentiments were shared, by and large, with the majority of the population.

As before, the 1998 tests were immediately condemned by a broad spectrum of the international community including the G-8, European Union, Organisation of American States, the Gulf Cooperation Council, the Organisation of the Islamic Conference, the Nordic Council of Ministers and 152 individual states. The United Nations Security Council (UNSC) issued resolution 1172 on 6 June 1998 which called upon both India and Pakistan to abandon any further testing, resume dialogue over Kashmir, stop their nuclear weapons programmes, end fissile material production, join the NPT, CTBT and participate in negotiations on a fissile material cut-off treaty and 'confirm their policies not to export equipment, materials or technology that could contribute to weapons of mass destruction or missiles capable of delivering them' (UNSC 1998; Synnott 1999: 28). Both countries came under a range of sanctions by 14 states, with the most serious applied by the USA and to a lesser extent Japan. The USA ceased development aid and new credit guarantees, suspended military sales, toughened export controls on dual-use equipment and also prevented private US banks from providing finance to both governments. These sanctions were designed to both bolster the credibility of the non-proliferation regime as well as to constrain an escalation in the nuclear competition between the two countries (Synnott 1999: 29). No consensus could be established, however, on a UNSC-based sanctions regime which was rejected by Russia, France and China. In the case of India, there was a concern that comprehensive economic sanctions might affect the poor disproportionately and reverse the difficult financial reforms put in place in 1991, which had reversed the long-standing commitment to self-reliance by opening the country to the global economy (Synnott 1999: 32).

Apart from sanctions, the USA, under the Clinton Administration, sought to use direct diplomacy to contain the Indian military programme. Soon after the May tests, US Deputy Secretary of State, Strobe Talbott, initiated a dialogue with the Indian deputy chairman of the Planning Commission, Jaswant Singh, to work towards the achievement of benchmarks mirroring those set out in UNSC Resolution 1172, the most important to the USA being Indian signature and ratification of the CTBT. Binding constraints were effectively sought on the Indian nuclear weapons programme, with the ultimate aim of 'roll-back', with the withdrawal of sanctions offered as a carrot. India refused to countenance roll-back but offered voluntary restraint by adopting a minimum credible deterrent nuclear posture and a 'no first-use' commitment in return for the removal of all sanctions, going back to 1974 (Mohan 2006: 19–20; Karnad 2008: 92). US insistence on India signing the CTBT was to ultimately founder with the US Senate's refusal to ratify the treaty in 1999 (Kimball 2005). Removal of the high technology sanctions were strongly opposed by the arms control establishment in the USA that viewed this as a reward for India's refusal to join and abide by the norms contained in the Nuclear Non-Proliferation Treaty.

Ending India's nuclear ostracism – the US–India civilian nuclear cooperation

The George W. Bush Administration finally ended India's nuclear ostracism. From the outset, the new administration sought to build a stronger bilateral relationship with India. Talks began on closer cooperation on 'a trinity of issues' (Mishra 2003), namely trade in high technology, space cooperation and civilian nuclear cooperation in November 2001 (Mohan 2006: 22–23). In September 2004, the two countries announced the details of the Next Steps in Strategic Partnership (NSSP) that included cooperation on all issues as well as intent to expand 'dialogue on missile defence'. The NSSP contained promises of the Indian government to strengthen controls to prevent weapons of mass destruction (WMD) proliferation, while the USA took steps to relax export licensing rules to 'foster cooperation in commercial space programs and permit certain exports to power plants at safeguarded nuclear facilities' with the latter referring to dual-use items not controlled by the NSG (Bureau of Industry and Security 2004). Such cooperation on high technology would have to take place within existing US laws.

It was not until 18 July 2005 that President Bush signalled the intention to take the momentous step to remove existing legal impediments to civil nuclear cooperation with India, thereby taking a significant U-turn in non-proliferation policy domestically and internationally. In a joint statement with Prime Minister Manmohan Singh, both countries declared a 'resolve to transform the relationship between their countries and establish a global partnership' (Embassy of India 2005). While a number of other broad-based economic, environmental, democratic and security-based objectives were announced, the most dramatic was the US pledge to commence *full* nuclear energy cooperation with India as a solution to the twin problems of energy security and climate change, with India being described as a 'responsible' nuclear power. In practical terms, full civilian cooperation would require the approval of the Congress, the agreement of the NSG to make an India-specific exception to their ban on trade in civilian technology and nuclear materials with non-NPT members, and the conclusion of a safeguards agreement with the IAEA (Embassy of India 2005).

Over the course of 2005–06, the Bush Administration set about ensuring that the domestic legal impediments to nuclear cooperation were overcome. The first step was to navigate the requirements of the Atomic Energy Act 1954 (AEA), as amended, which contains strict non-proliferation criteria on any civilian nuclear trade agreements, including the requirement that all trade with a non-nuclear weapons state be subject to full scope safeguards. After contentious congressional hearings, both houses passed unanimously the Henry J. Hyde US–India Peaceful Atomic Energy Cooperation Act 2006 (the Hyde Act) on 9 December 2006. The Act contained a series of conditions on any civilian nuclear trade with India (GovTrack 2006; Squassoni and Parillo 2006; Weiss 2007). Congress agreed to waive the requirement in the AEA that full scope safeguards be applied to any facilities/materials traded on the condition that India would:

- Provide a 'credible' plan to separate its civilian military nuclear materials, facilities and programmes and make a declaration of these to the IAEA.
- Conclude an agreement for the application of IAEA safeguards in perpetuity to its civilian nuclear facilities, materials and programmes.
- Make 'substantial progress' towards the conclusion of an Additional Protocol with the IAEA.
- 'Work actively' with the USA to conclude a multilateral fissile material cut-off treaty.
- Support US efforts to stop the spread of enrichment and reprocessing technology to any state that does not yet have them.
- Adhere to Missile Technology Control Regime (MTCR) and NSG guidelines in order to secure nuclear and other sensitive materials and technology.

The NSG would have to give permission for civilian nuclear trade with India (Hyde Act Section 104(b)(1)–(7)). The Hyde Act explicitly includes the requirement of termination should India detonate a nuclear device

(Section 106, Section 104(d)(3)). It also restricts the export of nuclear enrichment, reprocessing and heavy water technologies to India unless its purpose is to build a multinational facility, adequately safeguarded by the IAEA, using a proliferation-resistant fuel cycle (Section 104(d)(4)).

In the USA, the concern was raised that even if India was forced to separate its civil and military programmes/facilities, and place only the former under safeguards, without a stipulation that India freeze fissile material production, the deal would allow scarce domestic uranium resources to be reserved for the military programme, while US nuclear fuel supplies could be imported to supply the civilian programme. This was the precise course of action advocated publicly by K. Subrahmanyam,[1] the well-known nuclear advocate who wrote in *The Times of India* on 12 December 2005:

> Given India's uranium ore crunch, and the need to build up our minimum credible nuclear deterrent arsenal as fast as possible, it is to India's advantage to categorise as many power reactors as possible as civilian ones to be refueled by imported uranium and conserve our native uranium fuel for weapon-grade plutonium production.

In rejecting some amendments to the Act on these issues, Congress clearly understood that nuclear trade could potentially allow India to build its nuclear weapons programme.

Other concerns included the inability of IAEA safeguards to prevent the diversion of US-derived technology to the military programme and the adequacy of the separation plan. In particular, under this plan key elements of the nuclear programme would remain unsafeguarded (i.e. reserved for the military programme) including all elements of the fast breeder programme and existing enrichment and spent fuel reprocessing facilities. Thus, a significant proportion of India's nuclear programme would remain available for the production of fissile material for nuclear weaponry, particularly if the fast breeder programme reached its potential. Ultimately the advocates for the deal won the day on the grounds that India had proven itself to be a 'responsible' nuclear power (Sasikumar 2007: 829), and that it was better to bring India within the non-proliferation regime, albeit informally, than to continue a policy of isolation. Congress was further persuaded by the administration's view that the deal would enable the USA to develop stronger ties with a great power in the making that could potentially provide a valuable counterweight to a rising China in the region, which it had not yet definitively classified as a 'strategic ally' or 'strategic competitor' (Mearsheimer 2001: 101–102; Harvey 2003; Bromley 2008: 191–195; Tellis 2005: 55).

On the Indian side, debate was just as fraught with the primary consideration being whether the deal would constrain the future development of the military programme in particular, and in more general terms compromise India's cherished independent foreign policy making. In the parliamentary debates over the deal the Congress Party argued strongly that it would allow India to finally expand the share of electricity contributed by nuclear power, which was ever more essential to maintain the high level of economic growth and development experienced in the preceding years. In addition, nuclear power was argued to be both affordable and competitive with coal, while also being a 'clean source of energy' that would 'enable us to meet the twin challenges of energy security and environmental sustainability' (Congress Party 2007). However, the leftist parties within the United Progressive Alliance Coalition government did not believe that the economic, developmental and environmental arguments were persuasive. Remaining locked in a Cold War mindset, which preferred Indian non-alignment, they viewed the deal as a means by which the USA could exert pressure on India to take future actions contrary to the national interest (Chakravarthi 2009: 68). These parties pointed to the pressure exerted on India by the USA to refer Iran to the UNSC over its nuclear programme.

The most significant opposition party, the BJP, opposed the deal mainly on the grounds that it compromised India's future military needs by placing 'two-thirds' (*Sify News* 2006) of its power plants under safeguards in perpetuity (Kazi 2009: 85), and compromised India's 'right to test' (Chakravarthi 2009: 67). It argued that the deal should be renegotiated to remove any suggestion that India was legally bound to give up this right. On 22 July 2008, in a last ditch attempt to scupper the deal, the BJP joined the leftist parties in calling for a vote of no confidence in the government in the Lok Sabha. However, the collapse of the government was narrowly averted by a margin of 19 votes (in a total vote count of 487) because of a last minute defection by the Samajwadi Party (SP) (Chakravarthi 2009: 65; Kazi 2009: 96). The last remaining obstacle to the implementation of the deal was soon to be removed with the backing of strong US diplomatic pressure. On 6 September 2008, the NSG agreed to allow an India-specific waiver of the 1992 rule banning nuclear trade with NNWS unless they adopted full-scope safeguards (IAEA 1992). This was a considerable diplomatic success for India as no serious conditions were attached to the waiver, including any automatic termination provisions should it decide to conduct nuclear tests again. Further, on the issue of trade in sensitive technologies, the waiver simply requires members to 'exercise restraint'. All international impediments to civilian nuclear trade with India have thus now been removed.

Post-deal prospects for the nuclear energy programme

The connection between poverty, electoral success, economic growth and energy security

Before we turn to the implications of the nuclear deal and NSG waiver for the Indian nuclear energy programme, it is important to understand why the Congress Party risked the collapse of the United Progressive Alliance Coalition government, which it leads, in order to push through the nuclear cooperation agreement with the USA. The connection in India between electoral success, economic growth, the ability to provide higher living standards; access to basic services for a greater number, and energy supplies, is understandably strong. The scale of the problem of poverty in India remains large even though, according to the World Bank's figures, more than half of its population has been brought out of poverty over the last 62 years. As of 2008, 28 per cent of the rural population and 26 per cent of the urban population remained below the poverty line (World Bank 2008, 2009). Infant mortality was still high at a rate of 57 per 1,000 live births, while 46 per cent of children under the age of five were underweight (World Bank 2008). Literacy among the population as a whole over 15 stood at 61 per cent in 2007, with male adults having a literacy rate of 73 per cent and females 48 per cent. With a population of around 1.1 billion in 2007, the sheer numbers living below the poverty line highlight the extent of the problem of underdevelopment faced by the country. As such, Indian government planners openly acknowledge the real and pressing need to continue the path of economic growth in a manner that brings higher living standards and access to basic services such as health and education, to clean drinking water, sanitation, and reliable sources of energy supply to the greatest number (India Planning Commission 2006b).

Inroads into alleviating poverty have been made in recent times, especially since the start of reforms to liberalise the economy in 1991. Economic growth in India has accelerated significantly since 1997 with average GDP growth increasing from 5.5 per cent between 1997 and 2002 to 7.2 per cent in the period between 2002 and 2007 (India Planning Commission 2006b: 2). While the global financial crisis has taken a toll, with growth declining from a high point of 9.7 per cent in 2006–07 to 6.1 per cent in the quarter ending June 2009 (World Bank 2009), this is still an enviable result in the global context. Although this represents an objective indicator of good economic management by successive governments, the pressure of population growth and ever increasing numbers of young people entering the labour force with comparatively better skills and higher expectations than their predecessors means that future governments cannot afford to be complacent. Maintaining and increasing growth rates provide the key to the future prosperity of a larger proportion of the population. The Indian Planning Commission, for example, estimates that '[w]ith the population growing at 1.5 % per year, 9% growth in GDP would double the real per capita income in 10 years' (India Planning Commission 2006b: 2). Conversely, it is feared that a failure to sustain high levels of growth into the future will result in the demographic dividend turning into a demographic tinderbox with unmet expectations fuelling social and political unrest.

Electorally, all political parties have understood that their political fortunes are indelibly tied to their ability to deliver continuing high rates of economic growth but importantly to spread the benefits of such growth to the masses. Ensuring adequate energy supplies to fuel high growth rates, particularly electricity supplies, is thus central to any government's ability to fulfil its electoral promises. In the recent 2009 national elections the United Progressive Alliance coalition led by the Indian National Congress was returned to power with 262 seats out of 543 in the Lok Sabha (the lower house of Parliament). Importantly for the Congress Party, it is now able to govern with only three regional coalition partners and did not need to seek the support of the communist parties that had opposed the US–India deal. These parties lost the most seats compared with any other party, dropping from 43 to 16 seats (Ganguly 2009: 83).

While both the major parties, the BJP (BJP 2009) and the Congress Party, emphasised the importance of development, post-election analyses of the results attribute Congress's success to a party platform that sought to capitalise on the government's economic successes in the previous term and its championing of 'inclusive growth', with an emphasis on rural development. Given that almost two-thirds of the electorate come from poor rural areas, three election promises in particular were seen to give the Congress Party the edge: the promise to expand the existing rural infrastructure programme (the Bharat Nirman Programme – 'India Construction Programme'), directed towards the provision of 'irrigation, all-weather roads, houses for the poor, drinking water, electricity for all poor families and phone connectivity in all villages'; the National Rural Employment Guarantee Act that guaranteed 100 days of employment to each rural household in public works programmes at Rs 100 per day (Indian National Congress 2009: 11); and the writing off of farm debt of around 37 million farmer families (Ganguly 2009: 85; Indian National Congress 2009: 12).

An essential input required to deliver on the governing coalition's mandate to pursue 'inclusive growth, equitable development and a secular and plural India' (Patil 2009) is access to reliable sources of energy supply at competitive prices to both industry and households. Access to reliable energy supplies by the majority of the population has not yet been achieved. In 2000 'around 57% of the rural households and 12% of the urban households (i.e. 84 million households [more than 44.2% of the total] in the country) did not have electricity', while those who did have access experienced 'unscheduled outages, load shedding, fluctuating voltage and erratic frequency' of supply (India Planning Commission 2006a: 2). This has implications for both human development as well as economic growth with 86 per cent of rural households reliant on firewood, woodchips or dung cakes for cooking. This imposes a heavy burden on women and girls who are largely responsible for gathering fuel, and impacts upon the ability of the latter to access education (India Planning Commission 2006a: 6). While the challenge of providing reliable energy supplies is already real, it is expected to become even more challenging over the coming years.

The Indian Planning Commission projects that India will need to grow at between 8–9 per cent over the next 25 years in order to meet its development goals for a population expected to reach 1.47 billion (India Planning Commission 2006a: 68). Based on this calculation, the total primary energy requirement to sustain 8 per cent and 9 per cent growth, respectively, over this time period will mean that overall energy capacity will need to increase by 238 per cent and 271 per cent, respectively, between 2006–07 and 2031–32 (India Planning Commission 2006a: 31). What options does India have to meet its energy projected energy needs? India cannot be described as a particularly resource-rich country. It has very small reserves of crude oil, which if extracted in entirety, would be used within seven years going by consumption levels in 2004–05. Natural gas reserves have been boosted by recent discoveries but are still relatively modest. India's planners have hopes that hydro-electricity will play a greater role in managing peak demand. Hydro-electricity capacity in 2006 stood at around 32,000 MW at a 29 per cent load factor, with the potential to add a further 50,000 MW of new capacity by 2025–26. Hydro power has, however, natural limitations given the environmental impact and social resistance to the building of large dams in populated areas (India Planning Commission 2006a: 38).

The most abundant energy resource is coal, which should last for 45 years on the assumption that production levels grow at 5 per cent per year (India Planning Commission 2006a: 34). However, these reserves are 'of low calorie and high ash content' and are therefore expensive to extract (India Planning Commission 2006a: 33). Further, beyond this 45-year period, India will be forced to rely on imports of coal for electricity production with the attendant concerns about energy security in terms of increasing competition for coal resources on international markets and the ability to ensure consistent supply at a reasonable price. It will be impossible for India to avoid increasing its consumption of coal even with the full expansion and deployment of other renewable and non-conventional energy sources. Indian planners now look to the nuclear programme as a means to minimise the level of India's future reliance on imported coal for energy security reasons, for climate change reasons and for strategic reasons (Department of Atomic Energy n.d.a: 1, 15). The Congress Party has also now emphasised nuclear power as the solution to these three problems, with the growing middle class receptive to the view that their future prosperity is tied to the growth of the nuclear programme.

Nuclear power and energy security

In terms of nuclear-related resources, India has access to proven and potential nuclear fuel. It has poor natural uranium resources, with domestic supply able to fuel the production of 10,000 MWe by PHWRs running at a capacity of 80 per cent for 40 years (Grover and Chandra 2004). Indigenous ore is also of a low grade at around 0.1 per cent uranium, which makes production two to three times more expensive than international sources (India Planning Commission 2006a: 34–35). As mentioned above, India does have almost one-third of the world's reserves of thorium, a fertile element that can be used to produce nuclear energy once it is converted to uranium-233 in a nuclear reactor (Department of Atomic Energy n.d.b: 1). The three-stage nuclear plan put in place by Dr Bhabha still guides the development of the nuclear power industry to the present day, but only Stage 1 of the three-stage plan – the establishment of PHWRs using natural uranium to produce electricity – has been mastered and put into operation. The NPCI, a state-owned entity, operates 17 reactors – 15 PHWRs and two boiling water reactors (BWRs) – with a capacity of 4,120 MWe. As of 2009, construction was underway on three further PHWRs and two light water reactors (LWRs) (supplied by Russia) (Department of Atomic Energy 2009: 19), which would add a further 2,660 MWe capacity on completion.

Neither Stage 2 or 3 of the nuclear plan has been successfully implemented so far. In terms of Stage 2, in 1985 a fast breeder test reactor with a capacity to produce 40 MWe was built in Kalpakkam. Since then, in October 2004, construction began on a larger 500 MWe prototype breeder reactor also at Kalpakkam by Bhartiya Nabhikiya Vidyut Nigam Ltd, an entity wholly owned by the DAE, and is due for completion in 2010. The DAE plans to construct four more 500 MWe FBRs by 2020 (Department of Atomic Energy 2009: 36). None of the FBRs have been placed under the civilian list so far, but the Indian government reserves the right to do so. The third stage of the nuclear plan is still in the design phase with a low-power research reactor completed in April 2008 with the purpose of testing various physics designs for a thorium-based AHWR (Department of Atomic Energy 2009: 6). The DAE states that it has 'small scale experience over the entire thorium fuel cycle', citing the KAMINI reactor as 'the only currently operating reactor in the world which uses U233 as fuel' (Department of Atomic Energy n.d.b: 4).

In 2006, the Expert Committee of the Indian Planning Commission released its 'Integrated Energy Policy' in which nuclear power was viewed as an important source of electricity generation in the years up to 2050. As of 2009, however, nuclear energy contributed 4,210 MWe or a modest 2.6 per cent of India's installed electricity capacity of 156 GWe (Ministry of Power 2009). In 2006, *prior* to the completion of the US–India nuclear cooperation agreement, the DAE made aggressive projections about the future contribution of nuclear power to electricity capacity based on assumptions that 'the FBR technology is successfully demonstrated by the 500 MWe PFBR currently under construction, new uranium mines are opened for providing fuel for setting up additional PHWRs, India succeeds in assimilating the light water reactor (LWR) technology through import and develops the Advanced Heavy Water Reactor for utilising Thorium by 2020' (Table 4.1).

Table 4.1 The approximate potential available from nuclear energy

Particulars	**Amount**	**Thermal energy**		**Electricity**	
		TWh	**GW-yr**	**GWe-Yr**	**MWe**
Uranium-Metal	61,000-t				
In PHWR		7,992	913	330	10,000
In FBR		1,027,616	117,308	42,200	500,000
Thorium-Metal	225,000-t				
In breeders		3,783,886	431,950	150,000	Very large

Source: India Planning Commission (2006a: 36).

Electricity needs for the future are indeed considerable. To sustain an 8 per cent growth rate up to 2031–32, India needs an installed electricity capacity of 778 GWe, that is, to increase its electricity capacity by almost five times over the next 20 years (Table 4.2). In terms of the contribution that nuclear power can make to this task, optimistic projections of installed nuclear power capacity by 2030 are at 63 GWe, while the pessimistic projections are at 48 GWe (Table 4.1). If these projections come to fruition, nuclear power would potentially contribute 6–8 per cent of India's projected energy needs by 2032.

However, as the AEC's projections were made before the nuclear deal was concluded, they depend highly on whether Stages 2 and 3 of the nuclear plan are successfully implemented. In the pre-deal scenario, fast breeders would allow India to escape its uranium limitations. Without access to foreign sources of uranium, if the nuclear programme stayed at Stage I, where indigenous sources of uranium are passed through Indian-built PHWRs once with the spent fuel disposed of as waste, the contribution of nuclear power to electricity generation would not be able to exceed 10 GWe. If, however, stages 2 and 3 are successfully developed, breeder reactors are argued to be able to multiply the energy output of indigenous uranium resources 50-fold. The DAE estimates that with the use of FBR technology these uranium resources will be able to produce 20 GWe of power by 2020 (Table 4.1). Further, should more FBRs be built, based on indigenous thorium and plutonium bred from indigenously available uranium, about 500 GWe of power could be produced (Table 4.3) (Kakodkar 2005: 3). If so, India would not need to rely on imported sources of uranium and would be self-sufficient in nuclear power generation. This would reduce the Indian economy's exposure to increases in world prices for oil, coal and gas, which are widely predicted to rise as Asian economies progress along the development path. In addition, in the extreme case of major military conflicts – particularly blockages of supply routes by land and sea – erupting over access to energy supplies, nuclear power could provide a buffer to any supply disruptions.

Table 4.2 Projections for electricity requirements (based on falling elasticities)

Year	Billion kWh				Projected peak demand (GW)		Installed capacity required (GW)	
	Total energy requirement		Energy required at bus bar		@ GDP Growth Rate		@ GDP Growth Rate	
	@ GDP growth rate		@ GDP Growth Rate					
	8%	9%	8%	9%	8%	9%	8%	9%
2003	633	633	592	592	89	89	131	131
2006–07	761	774	712	724	107	109	153	155
2011–12	1,097	1,167	1,026	1,091	158	168	220	233
2016–17	1,524	1,687	1,425	1,577	226	250	306	337
2021–22	2,118	2,438	1,980	2,280	323	372	425	488
2026–27	2,866	3,423	2,680	3,201	437	522	575	685
2031–32	3,880	4,806	3,628	4,493	592	733	778	960

Note: Electricity generation and peak demand in 2003–04 is the total of utilities and non-utilities above 1 MW size. Energy demand at bus bar is estimated assuming 6.5 per cent auxiliary consumption. Peak demand is estimated assuming system load factor of 76 per cent up to 2010, 74 per cent for 2011–12 to 2015–16, 72 per cent for 2016–17 to 2020–21 and 70 per cent for 2021–22 and beyond. The installed capacity has been estimated keeping the ratio between total installed capacity and total energy required constant at the 2003–04 level. This assumes optimal utilisation of resources bringing down the ratio between installed capacity required to peak demand from 1.47 in 2003–04 to 1.31 in 2031–32.
Source: India Planning Commission (2006a: 20).

Table 4.3 Possible development of nuclear power installed capacity

Year	Unit	Scenario		Remarks
		Optimistic*	**Pessimistic**	
2010	GWe	11	9	These estimates assume that the FBR technology is successfully demonstrated by the 500 MW PFBR currently under construction, new uranium mines are opened for providing fuel for setting up additional PHWRs, India succeeds in assimilating the LWR technology through import and develops the AHWR for utilising thorium by 2020.
2020	GWe	29	21	
2030	GWe	63	48	
2040	GWe	131	104	
2050	GWe	275	208	

Note: * It is assumed that India will be able to import 8,000 MWe of LWRs with fuel over the next ten years.
Source: India Planning Commission (2006a: 37).

The nuclear deal and NSG waiver now gives India an alternative means to expand its nuclear power programme, without strict reliance on the success of the fast breeder programme, that is, to import nuclear fuel from the outside. Importation of reactors and fuel would allow the nuclear power programme to expand at a much greater rate than would otherwise be the case, but does not alleviate the potential exposure to energy insecurity if world uranium prices increased substantially, or if supply routes are blocked in the case of potential future military conflicts. For this reason, the nuclear establishment and the government are firmly committed to the breeder programme. As the fast breeder programme has potential military applications, none of these have been classified as civilian and are not under IAEA safeguards. Development of this programme will remain strictly in the hands of the government rather than private players.

While the fast breeder programme will continue to have government support, many are sceptical that it will ever play the role envisaged in India's three-stage plan (Ramana 2007: 78–79). The breeder reactor programme has suffered from a number of accidents and technical failures since work began, with the fast breeder test reactors taking 15 years to achieve criticality in 1985. Since then, the performance of the reactor has been described as 'mediocre' on the basis that it has 'operated for only 36,000 hours, i.e. at an availability factor of approximately 20%' from 1985 to 2005 (Cochran et al. 2010: 39). Following a similar pattern, the commission date for the PFBR has been pushed back a number of times with the latest date set at 2010. At present only three countries – India, China and Russia – have persisted in pursuing the development of fast breeder technology. Most other states that have had breeder programmes have now abandoned them in light of poor cost competitiveness with more traditional nuclear power generation options such as PHWRs, but also because of strong safety concerns.

Reactors in the USA, France and Japan have suffered from numerous accidents and incidents that required long shutdowns including a partial reactor meltdown in the case of the US Fermi FBR in 1966, a major sodium leak at the French Superphénix reactor in 1987 and a serious sodium leak fire at the Monju reactor in Japan in 1995 (Kumar 2009: 144–145; Cochran et al. 2010: 32, 54, 95). It is unnecessary to fully explain the science here, but FBRs are subject to two major safety challenges: 'large energy releases' in the event of a core meltdown with a greater potential to rupture protective barriers; as well as vulnerability to fires stemming from the use of sodium as coolant in the core (Kumar 2009: 146). Dealing with these safety concerns has also meant that containment costs, and therefore capital costs, are much higher for FBRs compared with other more traditional designs (Kumar 2009: 156). It remains to be seen whether the DAE is able to overcome its problems with reliability of design and safety.

While importation of foreign reactors does not resolve all aspects of the energy security problem, it does allow for the expansion of nuclear power at a much faster rate than would have been possible through reliance purely on the government-owned NPCI. It has also been argued that without importation of reactors it was unlikely that NPCI could meet the ambitious expansion targets set by the AEC on the basis of its past track record of over-promising and under-delivering. In 1954, on the basis that the three-stage nuclear programme had been successfully developed, it was projected that nuclear power would produce 8,000 MW of power by 1980. In 1962 these projections were revised to 20,000–25,000 MW by 1987, and again revised in 1969 with nuclear power predicted to generate 43,500 MW of power by the year 2000. None of these projections were even close to being met. While the Indian programme was hampered by the international technology denial regime, the DAE cannot complain of a lack of financial support by the central government, with its budget increasing from Rs 18.4 billion in 1997–98 to Rs 55 billion in 2006–07.

The Singh government has wasted no time in pursuing suppliers of nuclear power plants and fuel. On 30 September 2008, within weeks of the NSG decision, India had negotiated a civil nuclear cooperation agreement with France covering both trade in fuel and reactors. In December 2008, the French company Areva also agreed to sell NPCI 300 tonnes of uranium and signed a memorandum of understanding to negotiate the supply of six nuclear reactors of 1,650 MWe each (*Power Today* 2009). Russia has also sought to capitalise on the opening up of the Indian market, signing a nuclear cooperation agreement on the supply of nuclear power plants on 5 December 2008, while Russia's TVEL Corporation signed a nuclear fuel supply agreement with the DAE in February 2009. Other suppliers of uranium now include

KazAtomProm of Kazakhstan, while Namibia and Mongolia have agreed to allow India to pursue investment opportunities for the exploration of uranium (Kerr 2009: 26–27). It has been reported that India plans to import 24 reactors over the next 11–15 years with a total price tag of US$27 billion (Confederation of Indian Industry 2009).

The USA has yet to capitalise economically on the diplomatic efforts it has undertaken to release India from the international technology denial regime. Under the 10 September 2008 letter of intent delivered by Foreign Secretary Shivshankar Menon to the US government, India promised to purchase at least two nuclear power reactors with a minimum power generation capacity of 10,000 MWe (Bagchi 2009). Two nuclear reactor sites have been reserved for US firms in the states of Andhra Pradesh and Gujarat. However, trade has been held up because of the as yet unresolved issue of civil liability for nuclear accidents, with US companies refusing to enter the market without being shielded from potential prosecution (*Inside US Trade* 2009).

India has not yet signed and ratified the Convention on Supplementary Compensation for Nuclear Damage (CSC), which allocates legal liability for damage caused by nuclear accidents strictly to the operators of a nuclear installation and limits the liability to an amount specified in state legislation. Liability issues are not as important for trade with Russia or France, for example, where nuclear commerce is controlled by government-owned entities rather than private firms, which therefore have the backing of state resources should compensation be needed in the case of a nuclear accident (Casey 2008; *Times of India* 2009). India has stated its intention to sign the CSC and on 20 November 2009 the Indian Cabinet approved the Civil Nuclear Liability Bill under which the Nuclear Power Corporation of India would be liable as the operator (and not the foreign supplier) for the majority of compensation in relation to nuclear accidents, with a limit of Rs 2,250 crore (US$480 million), while the liability of the supplier would be capped to Rs 300 crore (US$64 million) (Chellaney 2010).

The passage of the bill at the next parliamentary sitting is likely given the Congress government holds a strong majority. However, things may not go smoothly for the government. The issue of corporate responsibility for environmental damage is highly contentious in India given that it was the site of the world's largest industrial disaster in Bhopal in which 3,800 people were killed by a cyanide leak at the pesticide plant operated by the American company Union Carbide Corp. in 1984. Up until this point there has been little opposition from civil society about the planned expansion of the nuclear power programme. For example, in a multinational survey taken of public opinion on nuclear energy in November 2008, Indian respondents were the most supportive of nuclear energy as a means of reducing fossil fuel reliance (alone or combined with other renewable energy sources) out of respondents from 20 other countries, with 67 per cent expressing a favourable view (Narayan 2009). Similarly, in response to the question of whether their country 'should start using or increase the use of nuclear power, either outright or if their concerns were addressed' 96 per cent of Indian respondents gave their support. However, it is notable that these 'concerns' included the disposal of nuclear waste, nuclear safety and the decommissioning of nuclear power plants (Narayan 2009).

It is likely that some Indian opposition parties and nuclear activists will mount a serious campaign opposing the bill (Devraj 2010), which has already been argued to lead to 'privatisation of profit and socialisation of risk' where suppliers provide substandard designs and equipment (*Hindustan Times* 2009; *India Today* 2009). Questions have also been raised about the adequacy of the liability cap contained in the bill, given that the 1979 Three Mile Island nuclear accident was reported to have cost US$1 billion to resolve (Chellaney 2010). The National Alliance of Antinuclear Movements has begun to mount a public campaign on the issue and has called for the establishment of criminal liability for companies supplying nuclear power plants, with direct reference to the Bhopal disaster.

Nuclear power as a solution to the problem of development and climate change

Apart from the potential contribution of nuclear power to energy security and economic growth, the Singh government has also advocated nuclear power as a solution to the problem of climate change (Indian National Congress 2007). In every future scenario projected by the Planning Commission in its 2006 report, coal provides the major source of energy for the Indian economy, even with the development of greater hydro-electricity, renewable and nuclear power (India Planning Commission 2006a: 46). In terms of world consumption of coal, India's present consumption of 6 per cent is estimated to grow to around 45 per cent by the middle of the century (Srinivasan et al. 2005: 5183–5188; Grover 2009: 31). Although nuclear power can never displace coal as the primary energy source for the economy, the Indian government argues that the development of the nuclear industry would reduce the country's relative contribution to climate change given that nuclear power is almost carbon neutral, emitting 9–100 g/kWh of carbon dioxide compared with 800–860 g/kWh from advanced coal (Sethi 2009: 44; World Nuclear Association 2009; Rogner et al. 2010).

Given that none of the commercial deals made after the US–India deal and NSG waiver have as yet been implemented, we can only estimate how much carbon abatement would be possible. In his testimony before the US Senate Committee on Energy and Natural Resources on 18 July 2006, David Victor predicted that new nuclear capacity resulting from the deal would fall within the range of 10–20 GWe by 2020, taking into account the past performance of the government-run nuclear power industry and the likely problems that may arise as power generation is opened up to the private sector. The then

Secretary of State, Condoleezza Rice, took a more optimistic view, stating to the Senate Foreign Relations Committee on 5 April 2006 that new installed capacity would reach 20 GWe. If Rice was optimistic, Indian Prime Minister Manmohan Singh went one step further, suggesting that the nuclear deal could lead to the expansion of nuclear power capacity by 40 GWe by 2015. Taking the middle path, Victor estimates that the displacement of 20 GWe produced via coal-fired power stations would abate 145 million tons of CO_2 per year, which represents 'the entire commitment of the 25 EU nations to reducing emissions under the Kyoto Protocol' and 'exceed the total carbon savings from the 100 largest developing country projects under the Kyoto Protocol's Clean Development Mechanism (CDM)' (Victor 2006: 5). As such, the potential impact of nuclear trade with India on climate change could be highly significant, particularly if Prime Minister Singh's ambitious expansion targets come to pass.

Conclusion

This chapter has demonstrated that the Indian nuclear story cannot be told without equal emphasis being placed on both its civil and military programmes. Throughout the history of the nuclear programme, Indian leaders have been united in their view that nuclear technology would provide the solution to the problems of development, energy security and independence, freedom from external 'nuclear' coercion, as well as providing a source of national pride and international prestige.

While the nuclear story was long dominated by the effects of the technology denial regime instituted after India's first nuclear weapons test in 1974, the agreement by the USA to begin full civilian nuclear trade has opened a window of opportunity for India to achieve its long held goal of achieving energy security and sustainable development. The nuclear deal and the subsequent NSG waiver now allow India to undertake a significant expansion of its nuclear energy programme by giving it access to foreign civilian reactor technology and nuclear materials of which it is naturally deficient. Given India's belatedly recognised status as the next great power and economic powerhouse in Asia, it has found itself inundated with willing suppliers of both reactors and fuel supplies.

It has been argued in this chapter that most impediments to the realisation of the government's ambitious expansion plans have been, or are likely to be, overcome. The only remaining doubts are whether the Nuclear Power Corporation of India can improve on its past poor track record of implementation of reactor projects in its partnerships with foreign suppliers and whether the tide of support for nuclear energy among the public can be sustained as land is appropriated, vastly increased numbers of reactors are rolled out across the country, and fears about nuclear accidents potentially take hold. Finally, it should also be noted that the end of India's nuclear ostracism now ushers in a new era in terms of the relevant players in the nuclear energy game within the country. The nuclear field has long been the preserve of a small cadre within the nuclear establishment – the AEC and DAE – and the prime minister and has largely been secluded from the pressures of public accountability. With the opening up of nuclear trade with the rest of the world, the nuclear establishment now has to share its influence in the energy field with private corporations and is likely to be subject to greater public scrutiny over its methods, efficiency and ability to deliver. In addition, as larger numbers of foreign and indigenously built PHWRs take a greater share of electricity production, questions will increasingly be raised about the comparative cost associated with the yet unrealised fast breeder programme. Nevertheless, the culture of self-sufficiency and self-reliance runs deep within the governing elites and strategic community, having been nurtured by decades of nuclear ostracism. This will be difficult to dislodge by simple cost benefit analysis. As a result, the potential military and energy security applications of a successful fast breeder programme will ensure that the nuclear establishment will continue to have strong relevance and influence over the future development of nuclear science and technology within India.

Note

1. K. Subrahmanyam was head of the National Security Council Advisory Board under the Vajpayee government tasked with drafting the Indian nuclear doctrine.

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5
Nuclear Energy Development in Japan

Toshihiko Nakata

Japan is extremely poor in natural resources, relying on imports for approximately 80 per cent of its primary energy requirements. In particular, nearly 90 per cent of its crude oil is supplied from the Middle East. Since the oil crises of 1973 and 1979, Japan has diversified its energy sources by introducing nuclear energy as well as liquefied natural gas (LNG) and coal. As a result, about 30 per cent of electricity in Japan now comes from nuclear power and the dependence on oil as primary energy supply has been lowered from 77 per cent in 1973 to 50 per cent in 2003.

Nuclear power generation in Japan

Following the end of World War II in 1945, Japan went through a period of occupation by the Allied Forces, a time of economic and social turmoil. Its re-emergence as a member of the international community started with the signing of a peace treaty with the world's leading countries in 1951 which was consummated when Japan became a member of the United Nations in 1956.

Japan has developed its research into nuclear power generation since the middle of the 1950s. A test power reactor, Japan Power Demonstration Reactor (JPDR), started operation in 1963 and Tokai Power Station, the first commercial reactor, went into commercial operation in 1966 with a generation capacity of 166 MWe. Currently, 53 commercial nuclear reactors are in operation, with a total generation capacity of 47,935 MWe, contributing to about 30 per cent of electricity production in the country. Japan will continue to develop nuclear power as a mainstay of non-fossil energy, while placing the highest priority on safety.

Beginning as a national strategy in the 1950s

A budget for nuclear research and development (R&D) was first presented to the National Diet of Japan in March 1954, and it was subsequently approved. Diet member Yasuhiro Nakasone first introduced the budget soon after he had visited nuclear facilities in the USA in 1953. Although at that time nuclear research had not gained public acceptance in Japan, Yasuhiro Nakasone consulted with Dr Ryokichi Sagane of Lawrence Berkeley National Laboratory in California and received advice on the use of nuclear energy. First, he was told, it is important to establish a national long-term strategy on nuclear energy. Second, nuclear R&D must be backed up with a sufficient budget and be enshrined in law. And third, the government should encourage the nation's best scientists and engineers to join the nuclear industry (Fukuda 2006).

Mr Nakasone was head of the executive board members of the House of Representatives Budget Committee and he had the budget enacted as swiftly as possible. Then, in December 1955, the government passed the Atomic Energy Basic Act through the Diet, in which it was proposed that 'nuclear energy development should be limited for peaceful utilisation under democratic control to secure safety, and the outcomes should be open to the public to promote international cooperation'. In September 1956, the Japan Atomic Energy Commission adopted its long-term plan for research, development and utilisation of nuclear energy, which stated that 'research, development and utilisation of nuclear energy are to strengthen energy security, to promote rapid economic development and an academic base, and to promote the welfare of the people. In order to develop domestic power reactor technology to meet Japan's situation, a nuclear industry and its technologies are to be established to provide support for fundamental research' (Pickett 2002).

Consequently, just ten years after its defeat in World War II, Japan accepted nuclear energy for the first time. In 1959, Mr Nakasone joined the Kishi Cabinet as Minister of Science and Technology, and acted as a chairman of the Atomic Energy Commission of Japan.

Nuclear energy and national character

Japan is the only country in the world that has been bombed with atomic weapons. Within the first few months of the bombings, 90,000–166,000 people died in Hiroshima and 60,000–80,000 in Nagasaki. Hundreds of thousands of survivors suffered radiation poisoning, many of whom succumbed weeks, months or even years after the war had ended. Nevertheless, Japan went on to become a nuclear energy power, building dozens of plants to provide electricity for the resource-poor nation.

Japan is committed to three non-nuclear principles: nuclear weapons shall not be developed, possessed or enter Japan. Today, Japan adopts diplomacy that takes these international conditions into account in pursuing its basic goal of ensuring the peace and prosperity of the country and its people. It stands on the foundation of the three principles of diplomacy, the Japan–US Alliance and the spirit of international cooperation, and vigorously strives to make humanitarian, material and financial contributions to the international community.

Nuclear energy is a controversial topic with the Japanese public and a variety of stakeholders. The government, inter alia, frequently releases information in the mass media in support of nuclear energy, provides a healthy budget for both the nuclear industry and nuclear engineer education at universities, supports local government funding and constructs visitor centres near nuclear facilities. These public assistance programmes are guaranteed by the so-called 'three sets of laws': the Act on Tax for Promotion of Power-Resources Development (1974), the Act on the Development of Areas Adjacent to Electric Power Generating Facilities (1974) and the Act on the Special Account for Power Sources Development (1974–2007).

At the time of the oil embargo in the 1970s, the government of Japan was urged to take new measures to deal with rising oil prices. The lights of Tokyo Tower were dimmed, and late-night TV shows were prohibited to save electricity across the country. It was then that nuclear energy gained full 'citizenship rights' to secure Japan's energy supply, but without any significant public debate taking place on the impacts of nuclear power on the environment. The Ministry of International Trade and Industry (MITI) waited for the opportunity to gain control of the nuclear industry, and increased its voice in the electric power industry. Japan was one of a handful of countries in the world at the time where private utilities dominated the electricity industry; in all others, the public-owned and vertically integrated utilities monopolised the sector. The electric power utilities started importing US-designed nuclear power facilities through the Japanese *sogo shosha* (general trading companies), and plants were constructed by the Japanese heavy manufacturing industries. It was a time when a bureaucrat-led economic structure had a passion for everything 'made in Japan'.

Buoyed by booming demand, the industry was revitalised by the vigorous introduction of advanced technologies and the building of many new and highly efficient nuclear power plants along the coast. The government was heavily involved in Japan's nuclear energy development: the manufacturing industry received administrative advice from MITI, transportation advice from the Ministry of Transport, communication advice from the Ministry of Posts and Telecommunications, and financial advice and subsidies from the Ministry of Finance. The Ministry of Foreign Affairs, although officially showing little interest in nuclear energy, helped build a nuclear cooperation deal with the US military. In short, it was the concerted effort between the government agencies and the industries that made Japanese nuclear energy development possible.

Today, the government involvement in the nuclear industry continues: the Ministry of Economics, Trade and Industry (METI) makes policies for nuclear development, and allocates funds for nuclear projects, provides subsidies and other support through some of the government-affiliated organisations, such as the Centre for Development of Power Supply Regions. The nuclear industry has been totally controlled by METI, albeit with fundamental contradictions in that METI has responsibility for both accelerating nuclear power plants and for nuclear safety regulation.

Despite the government's commitment to nuclear energy development and its generous assistance and tax incentives to the nuclear industry, the public has been sceptical about nuclear power, especially the radioactivity risk and safety concerns of nuclear power plants. The public anxieties are growing also because technical information on quantitative risk assessment is not available to the public. The key to understanding risks in nuclear energy is, in part, premised upon convincing citizens that they should not be sceptics and doubters – and therefore obstacles to progress – but rather catalysts, innovators and multipliers for a transition to a more energy-efficient society.

The diffusion of nuclear power stations during the 1960s–70s

Japan launched its nuclear programme in the middle of the 1950s. A test power reactor, JPDR, with the boiling water reactor (BWR) and capacity of 12.5 MWe, went into operation in 1963 under a joint project between the General Electric Company in the USA and the Japan Atomic Energy Research Institute (JAERI). General Electric designed the reactor, and Hitachi was in charge of building it. The Tokai Power Station, the first commercial reactor, went into operation in 1966 with a generation capacity of 166 MWe after additional earthquake protection, which was an advanced Calder Hall power reactor designed in the UK (Takuma 2005).

Since then, Japan has introduced two different types of US nuclear reactors: one is the BWR designed by General Electric and the other is the pressurised water reactor (PWR) designed by Westinghouse Electric Corporation. Unit No. 1 of the Tsuruga Nuclear Power Station (357 MWe, BWR), owned by the Japan Atomic Power Company, in which regional electricity utilities invested, started operation in March 1970. Unit No. 1 of Mihama Nuclear Power Station (340 MWe, PWR), owned by Kansai Electric Power Company, started operation in November 1970. Electricity utilities in the western part of Japan, along with the Hokkaido Electric Power Company, adopted PWR through Westinghouse. In contrast, the electricity utilities in the eastern part of Japan, such as the Tokyo Electric Power Company and the Tohoku Electric Power Company, adopted BWR through General Electric (Table 5.1).

Selection of nuclear sites is controversial in all countries and it is often more problematic in countries with dense population, as in Japan. The 'not in my back yard' mentality has been prevalent across the country and is one of the most difficult obstacles for nuclear energy development. Even to this day, there are serious concerns in the community, especially those within the vicinities of nuclear power plants. There have been clashes between

Table 5.1 Nuclear power stations in Japan

Type of reactor	Number	Capacity (GWe)
Boiling water reactor (BWR)	27	24.4
Advanced boiling water reactor (ABWR)	4	5.33
Pressurised water reactor (PWR)	24	19.7
Total	55	49.4

Source: Federation of Electric Power Companies (2009a).

pro-nuclear and anti-nuclear advocates resulting in the ostracism of people on both sides of the debate. The sites for the power plants were carefully chosen by local electricity utilities, which were indirectly supported by the government (Table 5.2).

The priority for choosing a suitable site is to find a coastal area where it is easy to obtain the necessary cooling water and is convenient for the transportation of building materials during a plant's construction, and to ship nuclear fuel waste. The priority would also be given to those areas where there are limited numbers of residents, and where possible collaboration can take place with local authorities. It is common for coastal villages that are experiencing a declining population to accept a nuclear plant on their

Table 5.2 Nuclear power stations by sites

Utility	Site	Unit	Capacity	Operation	Reactor
JAPC	Tokai	2	1, 100	1978	BWR
	Tsuruga	1	357	1970	PWR
		2	1,160	1987	PWR
Hokkaido	Tomari	1	579	1989	PWR
		2	579	1991	PWR
Tohoku	Onagawa	1	524	1984	BWR
		2	825	1995	BWR
		3	825	2002	BWR
	Higashidori	1	1,100	2005	BWR
Tokyo	Fukushima 1	1	460	1971	BWR
		2	784	1974	BWR
		3	784	1976	BWR
		4	784	1978	BWR
		5	784	1978	BWR
		6	1,100	1979	BWR
	Fukushima 2	1	1,100	1982	BWR
		2	1,100	1984	BWR
		3	1,100	1985	BWR
		4	1,100	1987	BWR

	Kashiwazaki-Kariwa	1	1,100	1985	BWR
		2	1,100	1990	BWR
		3	1,100	1993	BWR
		4	1,100	1994	BWR
		5	1,100	1990	BWR
		6	1,356	1996	ABWR
		7	1,356	1997	ABWR
Chubu	Hamaoka	1	540	1976	BWR
		2	840	1978	BWR
		3	1,100	1987	BWR
		4	1,137	1993	BWR
		5	1,267	2005	ABWR
Hokuriku	Shiga	1	540	1993	BWR
		2	1,358	2006	ABWR
Kansai	Mihama	1	340	1970	PWR
		2	500	1972	PWR
		3	826	1976	PWR
	Takahama	1	826	1974	PWR
		2	826	1975	PWR
		3	870	1985	PWR
		4	870	1985	PWR
	Ohi	1	1,175	1979	PWR
		2	1,175	1979	PWR
		3	1,180	1991	PWR
		4	1,180	1993	PWR
Chugoku	Shimane	1	460	1974	BWR
		2	820	1989	BWR
Shikoku	Ikata	1	566	1977	PWR
		2	566	1982	PWR
		3	890	1994	PWR
Kyushu	Genkai	1	559	1975	PWR
		2	559	1981	PWR
		3	1,180	1994	PWR
		4	1,180	1997	PWR
	Sendai	1	890	1984	PWR
		2	890	1985	PWR

Source: Federation of Electric Power Companies (2009a).

doorstep in order to revitalise their area. Huge government subsidies, as well as a fixed property tax, were initially attractive incentives for local governments to support the projects. Along with the decrease in the revenue of property tax with depreciation of the plant, some local governments even accepted more nuclear plants in their region (Figure 5.1).

Lying on the Circum-Pacific earthquake zone, the Japanese Archipelago is not only the site of considerable volcanic activity but is also one of the world's most seismologically active areas. Severe earthquakes that have hit

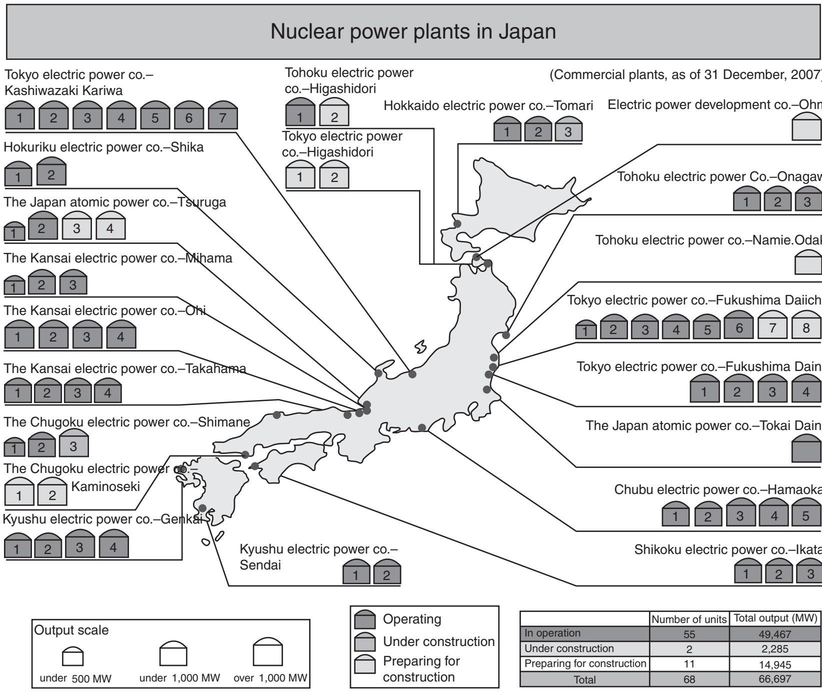

Figure 5.1 Nuclear power plants in Japan
Source: Federation of Electric Power Company (2010).

Japan since the beginning of the twentieth century include the Great Kanto Earthquake of 1923 (magnitude 7.9), which caused extensive damage over a wide area including Tokyo: the Niigata Earthquake of 1964 (magnitude 7.5), the Great Hanshin Earthquake of 1995 (magnitude 7.2), which devastated much of the Hanshin area including Kobe and Awaji Island, and the Mid Niigata Prefecture Earthquake of 2004 (magnitude 6.8), which ravaged the central region of Niigata Prefecture. More recently, the Niigata Prefecture Chuetsu-oki Earthquake occurred in 2007 (magnitude 6.8).

Although sites for nuclear facilities have been chosen carefully, the Niigata Prefecture Chuetsu-oki Earthquake directly hit the Kashiwazaki-Kariwa site, which has seven reactors with a total capacity of 8.2 GWe. All of the reactors were struck and resumed operations after extensive repair works for a few years.

Nuclear after the oil embargo

The first oil crisis in 1973 caused serious problems of electricity supplies in Japan because of its heavy reliance on imported energy. The government

Table 5.3 Changes in growth rate of GDP and energy supply

	1965–73	1973–79	1979–2000	1990–2000	2000–05
% GDP	9.1	3.7	3.8	1.2	1.3
% Total primary energy supply	10.9	1.1	1.5	1.4	0.3
Energy elasticity	1.2	0.29	0.40	1.21	0.21

Source: EDMC (2009).

adopted an emergency plan as a countermeasure for its limited petroleum import. In the plan the government made it clear that it would strongly promote nuclear power, and restrict the building of additional oil power stations. Also because of the crisis, energy saving technologies were quickly developed and then transferred from research labs to industrial application. This led to a significant reduction in energy intensity (Takase and Suzuki 2010), as shown in Table 5.3.

The Chernobyl accident in the USSR in April 1986 made a strong impact on Japanese public attitudes towards the safety and risk-sensitive issues concerning nuclear power. At the time of the Chernobyl accident, Japan was strongly embracing nuclear power. The industry with the support of the government moved very quickly in making siting and feasibility studies; purchasing land for nuclear power sites; and licensing, constructing and commissioning sites.

Despite government support for the nuclear programme and the provision of a range of assistance to the nuclear industry, it was the utility companies that, at least in public, made decisions on these site selections and projects because all nuclear projects were politically sensitive to politicians and the government. After the Chernobyl disaster, even the utility companies slowed down their activities regarding nuclear development due to safety concerns. In the 1990s, the Japanese economy, which had delivered astonishing successes in the 1960 and 1970s, fell into a long-lasting economic recession. As demand for electricity declined, so did demand for additional nuclear power plants, bringing a sense of unprecedented gloom to the domestic nuclear industry.

Electric utilities in Japan

Regional monopoly and liberalisation

Nine regional electric power companies (Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku and Kyushu) were established as private enterprises in 1951. As the core research centre, the Central Research Institute of Electric Power Industry was created at the same time to promote R&D in engineering and management related to the electricity industry.

With the return of Okinawa to Japan in 1972, Okinawa Electric Power Co. became the tenth regional utility. This structure remains to this day.

In 1998, the government planned for partial liberalisation of its electricity supply industries to promote competition among regional utilities and to encourage new enterprises to enter into the electricity market for conservation purposes. Consumers who used more than 2 MW of electricity could have direct access to power generation and they would be eligible to choose their supplier. These consumers account for about 30 per cent of total electricity demand. In addition, plans were put in place for third party access to the grid. Other related measures included a re-examination of the electricity rate (tariff) system, the introduction of a full-scale bidding system for the development of thermal power, and the removal and simplification of some administrative procedures and rules to ensure transparency in transactions.

In March 2000, partial liberalisation began for the power retail supply of large consumers of electricity. The Electricity Industry Committee, which was a part of METI, verified the current scheme and discussed how the electric power industry should operate in the future. The committee proposed the establishment of a Japanese model, maintaining a conventional vertical integration of generation, transmission and distribution in light of a stable supply of electricity. As a result, the revised Electricity Utilities Industry Law was promulgated in June 2003 and the scope of liberalisation was expanded on two further occasions, first in April 2004 and again in April 2005. During this time, there were frequent blackouts in New York and San Francisco, and fears of similar problems in Japan made it difficult to complete the liberalisation of the electricity market.

The gradual move towards the liberalisation of the electricity market has brought about a transformation in regional utilities. The big three utilities – the Tokyo Electric Power Company, the Kansai Electric Power Company and the Chubu Electric Power Company – struggled to compete with energy markets. On the resources side, they have access to LNG markets and compete against regional gas companies such as the Tokyo Gas Corporation, the Osaka Gas Corporation and the Toho Gas Corporation in Nagoya. On the demand side, electricity utilities strongly promote heat pump water heaters for users as an incentive measure to supply surplus electricity after midnight. Nuclear power stations in Japan are only allowed to operate at a rated peak power output on a base-load, resulting in an excess output after midnight and at weekends. For electricity utilities in a liberalised electricity market, the aged nuclear power stations become less attractive in terms of economic potential.

Physical constraints

Currently, the ten regional electric power companies are responsible for providing transmission services from power generation to distribution and supplying electricity to their respective service areas. In addition, they cooperate with each other to ensure a stable supply to customers nationwide, especially in emergency situations resulting from accidents, breakdowns or summer peak demand. To ensure the smooth operation of power exchange, extra-high voltage transmission lines link the entire country from Hokkaido in the north to Kyushu in the south.

However, Japan's utilities have much work to do. Power frequency is 50 Hz in the eastern part of Japan and 60 Hz in western Japan. In order to connect these two power networks, frequency converters were installed in Sakuma and Shin-shinano, which only have limited capacities of 300 MWe and 600 MWe, respectively. When, in March 2003, the Tokyo Electric Power Co. was forced by METI to close all its nuclear power plants temporarily because of its concealment of nuclear plant problems, most of the company's backup electricity was coming from the Tohoku Electric Power Co., which had the same frequency and had excess generation capacity at the time. The transmission capacity between Hokkaido and Tohoku in the north is limited to 600 MW, and that between Kansai and Shikoku in the west is limited to 1,400 MW. Due to these constraints, utilities are eager to expand their facilities under their responsibility. Given the location of nuclear power plants along the coast and the concentration of some of them, electricity supplies from these nuclear power plants can be constrained by the existing transmission and distribution systems that do not have the same carrying capacity.

One indication of the constraints is that the energy availability factor of Japan's nuclear power plants is nearly as good as its neighbouring countries, China, South Korea or Taiwan (Table 5.4).

Indeed, its capacity utilisation rate improved from 60 per cent in 1980 and reached 80 per cent in the mid-1990s but then declined again back to 60 per cent in 2003 and 2007 (Figure 5.2).

Stakeholders in nuclear power

In the process of nuclear power planning, the selection of a site, and construction and operation, the government requires that utilities implement rigid examination and screening procedures. Related government organisations include the Japan Atomic Energy Commission (JAEC), the Nuclear and

Table 5.4 Lifetime energy availability factor

	World average	China	India	Japan	S. Korea	Taiwan
EAF (%)	77.1	83.2	59.4	72.1	87	82.6

Source: IAEA Power Reactor Information System at http://www.iaea.org/programmes/a2/, accessed on January 2010.

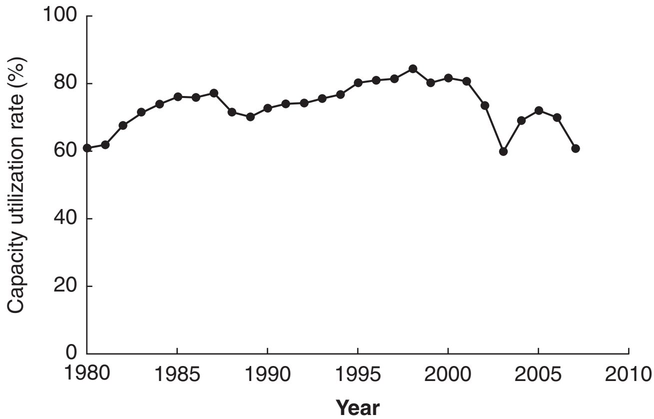

Figure 5.2 Changes in operating rates of nuclear power stations
Source: Japan Atomic Energy Commission (2009).

Industrial Safety Agency (NISA), the Nuclear Safety Commission of Japan (NSC) and the Japan Nuclear Energy Safety Organisation (JNES), an incorporated administrative agency. The JAEC was incorporated by law in January 1956. It was created under the auspice of the government's Cabinet Office. It was designed to pursue a national nuclear energy expansion in a democratic manner.

The NISA was established in January 2001 as part of a reorganisation of central government ministries under METI. Its mission is to ensure public safety by the regulation of the energy industry and related industries. The NSC was established in 1978, and it took over the function of ensuring nuclear safety from the JAEC in order to strengthen the nuclear safety administration system. The function of the NSC was transferred to the Cabinet Office in 2001 as an independent agency, and the NSC began to review and audit the subsequent regulations on construction and operation of nuclear power plants. The JNES, an incorporated administrative agency, was established on 1 October 2003 to issue licences on nuclear safety, conduct safety analyses, evaluate the design of nuclear installations and nuclear reactor facilities, and inspect nuclear installations and nuclear reactor facilities. The JNES is linked with the NISA and METI.

On 11 October 2005, the Atomic Energy Commission of Japan adopted a framework for nuclear energy policy which was approved by the Cabinet on 14 October 2005 (Table 5.4). Basic political measures for promoting nuclear power generation and improving radioactive waste management would be effective for ten years (Table 5.5).

As for an Environmental Impact Assessment (EIA), the government still hesitates to adopt the Strategic Environmental Assessment (SEA), which

Table 5.5 Basic political measures for nuclear energy in Japan

National policy	Definition
Objective of nuclear power generation	1. Contribute to energy security. 2. Contribute to prevention of global warming. 3. Promote the nuclear fuel cycle to improve the stable supply of nuclear power generation.
Objective of radiation application	1. Application of radiation in various fields including industrial and medical users will help improve public health and living standards. 2. Application of radiation in cutting-edge technologies and various industrial users is expected.
Basic policies in promoting nuclear energy	1. Assurance of safety. 2. Commitment to peaceful use. 3. Assurance of human resources. 4. Coexistence of nuclear energy and civil society. 5. Promotion of R&D. 6. Promotion of international initiatives.
Political measures	1. Maintain or increase nuclear power's share of 30–40 per cent or more of Japan's total power generation beyond 2030. 2. Effective use of plutonium and uranium by reprocessing spent fuel. 3. Aim to introduce fast breeder reactors on a commercial basis from around 2050. 4. Promote understanding and cooperation on the geological disposal of high-level radioactive waste.
Final target	Aim at effective and efficient application of radiation by developing advanced facilities under a strict safety assurance system.

Source: Federation of Electric Power Companies (2010).

is a system of incorporating environmental considerations into policies, plans and programmes. For the most part, an SEA is conducted before a corresponding EIA is undertaken. This will mean that information on the environmental impact of a plan can cascade down through the tiers of decision making and be used in an EIA at a later stage. This should reduce the amount of work that needs to be undertaken. The Ministry of the Environment has adopted a positive stance for introducing an SEA.

Meanwhile the government continues the Project EIA, in which large-scale infrastructure projects such as nuclear power stations are assessed under the METI. The Ministry of the Environment can only make their views known to the METI. The METI's dominant position is established by the Electricity Business Act 1964 where 'a person who intends to conduct an electricity business shall obtain a licence from the Minister of Economy, Trade and Industry'. In October 2005, responsibility for nuclear power R&D was transferred to the Japan Atomic Energy Agency (JAEA), a new independent government corporation set up by integrating the Japan Atomic Energy Research Institute and the Japan Nuclear Cycle Development Agency.

Government policy in nuclear energy

Since Japan needs to import some 80 per cent of its energy requirements, its energy policy has largely been driven by the concerns of securing energy supplies. Without nuclear energy, the import figure would rise to 97 per cent. This is also the main reason Japan has become the third largest nuclear energy producer in the world behind the USA and France.

In June 2002, the government enacted the Basic Act on Energy Policy, which states: 'With regard to energy supply and demand, measures shall be promoted to realise energy supply and demand that allow for the prevention of global warming and the preservation of the local environment, as well as to contribute to the formation of a recycling society by improving energy consumption efficiency, by such measures as promoting the conversion to non-fossil-fuel energy use such as solar and wind power and the efficient use of fossil fuels.' A ten-year energy plan was adopted by METI calling for an increase in nuclear power generation of about 13 GWe, with the expectation that 9–12 new nuclear power plants would be in operation by 2011. However, there have been delays in its implementation. Japan is promoting the Fast Reactor Cycle Technology Development Project with the objective of conceptually designing a fast reactor and its fuel cycle system by 2015, operating a demonstration reactor by 2025 and commercially deploying fast reactors around 2050.

In 2007, Japan's Agency of Natural Resources and Energy issued the Basic Energy Plan in which nuclear power was prioritised as an energy source that could help the country reduce carbon emissions (EPRI 2008) and as a 'quasi-domestic' resource to ensure energy security (Sato et al. 2000). The government and electric utilities often describe nuclear energy as 'quasi-domestic' because fuel reprocessing will produce recycled fuel in the near future (see Chapter 6).

Nuclear energy and society

Nuclear power has provided a stable supply of electricity independent from the availability of fossil fuels. However, although it has undoubtedly contributed to national energy security, the introduction of nuclear power has caused an unprecedented level of debate, friction and confusion in society.

Technical problems

The first technical problem encountered is that uranium enrichment technology has been introduced by a private company, Japan Nuclear Fuel Limited (JNFL), whose shareholders are regional utilities. The Rokkasho plant in Aomori Prefecture provided an ultimate capacity of 1,500 tonne-SWU/year, enough to meet one-third of the fuel demands of nuclear power plants in Japan. Currently, the Uranium Enrichment Plant is operating with a capacity of 1,050 tonne-SWU/year, which is equivalent to the nuclear fuel used by eight or nine reactors at 1,000 MW-class nuclear plants. Minimising proliferation risks is a priority at the Uranium Enrichment Plant (Katsuta 2010).

The next technical problem is that the technology transfer of the nuclear power industry is still under discussion. Japan imported a light water reactor from the USA, when Toshiba, Hitachi and Mitsubishi Heavy Industry were technically supported by General Electric and Westinghouse. Following the acquisition of British Nuclear Fuels Limited (BNFL) and Westinghouse in February 2006, Toshiba has risen to the position of the leading Japanese company in nuclear engineering on the international market. Toshiba has focused on BWR technology and aims to be a world leader in the nuclear industry by taking over PWR technology from Westinghouse.

Under these international initiatives, the nuclear industry has become more competitive in world markets. The Japanese nuclear industry has formed technical associations and partnerships with other companies to strengthen its technical capacity, which will enable it to gain a larger share of the global market. It remains to be seen whether its nuclear industry can be as successful and competitive as the Japanese automobile and electronics industries. Part of the problem is that even after Toshiba acquired Westinghouse as a majority shareholder, Westinghouse won global orders with its own name. For example, when China decided to import Generation III reactors, Westinghouse AP1000 was in the bidding ring. In the negotiation process, Toshiba won the bid to acquire Westinghouse. China was about to pull out of its negotiation with Westinghouse because of the domestic opposition to the ‘potential’ of the Japanese taking over the Chinese nuclear industry. Westinghouse then had a separate deal with Toshiba that it would bid for new nuclear projects under its name.

American and Japanese companies such as General Electric–Hitachi and Westinghouse–Toshiba have had a long history of collaboration in the nuclear industry. The global nuclear market is dominated by a few conglomerates and this has only intensified competition. The Japanese firms have to compete with the ‘old’ players, such as Westinghouse and Areva, as well as the ‘new ones’ such as the Korean companies and others which try to capture the world market on small- to medium-sized reactors. Nevertheless, the competitive nature of the nuclear industry is similar to that of other global businesses.

Other problems that need to be considered include nuclear plant safety and security, the possibility of human error at nuclear power plants and the concealment of technical information. The nuclear industry tends to be inward looking and conservative, even though it operates with a huge budget. Many technical managers in the industry graduated with the limited number of nuclear engineering courses available in Japanese universities.

In addition to these technical issues, the nuclear industry has experienced problems with its public image. Nuclear engineers and utilities have repeatedly stressed that nuclear reactors are safe but have failed to outline any of the risks involved in a qualitative or quantitative way. Because the METI has the responsibility to both promote and monitor Japan's nuclear industry, many argue, this is like 'to ask the fox to guard the henhouse'. It is important to bolster government surveillance of the industry with a more independent agency.

Environmental problems

The nuclear power industry has always struggled to come to terms with environmental pollution that results from nuclear waste. Japan has adopted a closed nuclear fuel cycle policy, and because it lacks sufficient natural resources, it has decided to recycle spent nuclear fuel domestically in order to establish nuclear power as a home-grown energy source. The closed nuclear fuel cycle has several potential benefits for Japan: it adds to the long-term energy security by reducing dependence on imported fuel; it conserves uranium resources; and it reduces the amount of high-level radioactive waste (HLW) that must be disposed of. Reprocessing is a chemical process that recovers plutonium and reusable uranium from spent fuel and separates radioactive waste into more manageable forms.

In the past, Japan has relied on countries such as the UK and France to reprocess most of the spent fuel it produced. However, to place Japan's domestic nuclear fuel cycle on a firmer footing, JNFL was undergoing test operations at a reprocessing plant in 2009 at a site in Rokkasho in the northern prefecture of Aomori. All of the core technology of fuel reprocessing comes from the La Hague plant in France, run by Areva NC, apart from a glass-melting furnace that was designed by the JAEA. The reprocessing plant is still in the final commissioning test stage because of the serious problems it has experienced with the melting furnace. The maximum reprocessing capacity of the plant is 800 tonnes uranium per year, enough to reprocess the spent fuel produced from 40 reactors at 1,000 MW-class nuclear power plants. That is almost equal to 80 per cent of the annual spent fuel generation in Japan. In addition, JNFL engages in temporary storage of vitrified waste and the disposal of low-level radioactive waste, and has plans to construct a MOX fuel fabrication plant.

The Specified Radioactive Waste Final Disposal Act was enacted in June 2000 and the Nuclear Waste Management Organisation (NUMO) was established to manage the high-level waste final disposal project in October 2000. The NUMO is now inviting municipalities to volunteer as candidate repository sites. It will promote the disposal project that includes investigation, selection of disposal sites, construction and operation.

Thus, nuclear waste disposal and fuel reprocessing are at the heart of sustainable nuclear energy. However, both remain in an extremely precarious state, with technical problems as well as a lack of public acceptance. Professionals in the nuclear industry have been forced to push back their target date for completing the nuclear fuel cycle.

Change in society

Nuclear energy has been a social issue since the 1970s. At that time, the public knew little about the risks involved in nuclear reactors, but they were told that nuclear power plants were perfectly safe (Lesbirel 1990). Furthermore, the public was not consulted on the projects. In the relatively poor regions where the sites were selected for nuclear power plants, local people found it difficult to resist compensation payments, and indeed, any opposition to nuclear energy could have led to them being ostracised in their rural area.

On the local administration side, it was difficult to change or oppose nuclear plant planning set by the METI and utility companies. Until about a decade ago, it was taboo for the public to criticise the administration's energy policy, which placed great emphasis on nuclear energy. By the late 1990s, the government started to recognise the importance of public acceptance of nuclear power. Discussion on the risks involved started in the 2000s, but the government hesitated in introducing risk information to nuclear power management. Risk-based regulation and risk management are not yet introduced to decision makers in the nuclear industry.

Some professionals in the nuclear industry doubt the effectiveness of risk communication between themselves and the public. They prefer to make decisions on nuclear planning without public consultation, because they believe they are the only people who understand the complex technical knowledge of nuclear engineering. They do acknowledge the risks involved in nuclear energy development among themselves, but believe that lack of understanding of the intricate technology among the public only creates more fear and anxieties.

There has been an increasing recognition that the spread of information on risk and promoting a more positive discussion on the benefits of nuclear energy to society are necessary for a nuclear expansion. In Japan, for better or for worse, nuclear has been given a special treatment, and its expansion depends on better cooperation between the government, industries, academia and the public.

The government has adopted a policy promoting 'the smart grid' system that will have position impacts on nuclear expansion once in place. The smart grid system is an automated and widely connected energy delivery network. It is characterised by a two-way flow of electricity and information, and incorporates into the grid the benefits of distributed computing and communications to deliver real-time information. The smart grid system would allow consumers to monitor in real-time how much power they are consuming and at what cost, which ideally leads to a reduction in peak and overall demand. A smart grid system can also accommodate energy from diverse fuel sources, including renewables such as wind and solar. Through an efficient balance between supply and demand, and the use of renewable as an energy source, smart grids can help reduce greenhouse gas emission. The smart grid system is also promoted in South Korea now as a way to deal with the twin challenges: energy security and climate change.

In August 2009, a general election was held for all 480 seats of the House of Representatives, the lower house of the Diet of Japan. The opposition Democratic Party of Japan (DPJ) defeated the ruling coalition of the Liberal Democratic Party (LDP) and the New Komeito Party. The LDP had ruled Japan as a one-party government since 1955. It was the first time in the post-war era that a change in government had taken place because of the opposition party winning a majority of seats.

In the DPJ's election manifesto, the energy policy was to 'increase the ratio of renewable energy to total primary energy supply to around 10% by 2020, while placing safety first and gaining the understanding and confidence of the people, and taking steady steps toward the use of nuclear power'. The party also announced that 'in order to prevent global warming, the aim is to reduce CO_2 emissions by 25% (from 1990 levels) by 2020 and by more than 60% (from 1990 levels) by 2050'. While these targets are clear, the DPJ's energy policy goals are not as ambitious as those of the USA and European Union countries. Japan has not changed a word of its nuclear policy since the policy came into existence at the end of World War II almost 65 years ago, and any amendments to this policy are likely to be a major topic of national debate.

Nonetheless, Japan, the only country in the world to have suffered nuclear bombing, has developed a successful nuclear industry – that is, following the initial advice of Professor Ryokichi Sagane in the 1950s, Japan established a national long-term strategy on nuclear energy, national financial support for nuclear R&D and a strong government–academia–industry alliance of its nuclear scientists and engineers. While the public support for nuclear energy might have been undermined by the illegal management scandal involving the nuclear industry, by the concerns over nuclear-energy-related environmental issues, and by the decline in electricity consumption caused by the prolonged economic recession, the nuclear industry is still expanding and nuclear energy remains a large contributor to the Japanese energy mix.

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6
Japan's Commitment to Nuclear Power: Grand Scheme or Pipedream?

Jeff Graham

Introduction

Japan has been committed to the development and use of nuclear power since the mid-1950s. In contrast to the majority of other major developed nations, this commitment, especially that concerning Japan's central government, has been unwavering. Its commitment has not been negatively affected by local or overseas reactor accidents, community protests, or managerial incompetence and cover-ups on the part of electric utility companies in charge of running conventional nuclear reactors and other nuclear facilities in Japan. Nor has it been affected by a growing body of analysis from academic, media and non-government organisational circles that questions the economic, environmental and safety rationales of government support for nuclear power, especially where such government support significantly outweighs that for improvements to the expanded use of alternative, renewable energy sources, as is the case in Japan.

From the 1980s through to the turn of the century it appeared that among the major industrialised nations Japan was the 'odd man out' in terms of its unrelenting push for the roll-out of nuclear power plants, and its ongoing pursuit of the so-called closed nuclear fuel cycle, especially in relation to its development of commercial reprocessing and fast breeder reactors (FBRs). On the conventional nuclear power plant front, the actions of various Western governments have reflected on-and-off and on-again pro-nuclear power policy stances. After the initial period of growing worldwide enthusiasm for the development of nuclear power from the mid-1950s through to the late 1970s, during the 1980s and 1990s the situation dramatically changed. A global love affair with relatively cheap fossil fuel based electricity generation, combined with a backlash to the 1979 Three Mile Island and 1986 Chernobyl nuclear reactor accidents, set in motion a nuclear power plant approval freeze in some countries, or in the case of others, an approval freeze along with pledges to phase out nuclear power within the early decades of the twenty-first century. Countries which fell into one or

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both of these nuclear power policy categories included, among others, the USA, Britain, Germany, Sweden, Switzerland, Holland and Belgium.

Since the turn of the century, however, the combination of rising energy security concerns in the midst of an emerging supply and demand side energy crisis, and increasing pressure to reduce greenhouse gas (GHG) emissions under the Kyoto Protocol and its expected successor regime, has induced many of these same Western governments to revisit the nuclear power option in what some have termed, rightly or wrongly, a nuclear renaissance (Australian 2006; Ford 2006; EBR Staff Writer 2007; Booth 2008; Lawless 2008; Stellfox 2008). While Japan's ongoing roll-out of conventional nuclear power plants simply represents a relatively unwavering commitment, its long-term focus on FBR development is somewhat more unique, in the sense that Western countries such as the USA, France, Germany and the UK have essentially abandoned FBRs due to their excessive costs, technological challenges and safety concerns. Furthermore, Japan's commitment to large-scale domestic reprocessing of spent nuclear fuel is unique in that it is the only non-nuclear weapon state to receive the consent of the USA and the International Atomic Energy Agency (IAEA) to enrich uranium and reprocess spent fuel at a commercial level. This unique status is highlighted by the fact that Japan now possesses close to 50 tonnes of weapons-usable plutonium. By 2020 this amount could be between 145 and 160 tonnes, which would mean Japan's stockpile of plutonium would be greater than that of the US nuclear arsenal (Katsuta and Suzuki 2006: 21; McCormack 2007).

Despite Japan being one of the most mature and technologically advanced economies in the world, and a country with a rapidly ageing and now shrinking population – hence potentially diminishing demand for energy over coming decades – any policies from the central government to follow a German or Danish-like aggressive, new-age push towards a twenty-first century electricity grid powered largely by renewable energy alternatives have been relatively non-existent. Instead, Japan has pushed aggressively towards an electricity grid based largely on nuclear power, and if all goes to plan, by the end of the twenty-first century a grid fuelled and powered to a large extent by spent fuel reprocessing facilities and a growing number of nuclear fuel-creating commercial FBRs (Nuclear Energy Policy Planning Division 2006). The following discussion examines the background factors and emerging elements of this ambitious commitment to nuclear power on the part of Japan's central government, and the relevant Japanese semi-government and private sector organisations.

The key actors and stakeholders

The key nuclear energy and safety policy making and implementation organisations within the Japanese government are the Japan Atomic Energy Commission (JAEC), Nuclear Safety Commission (NSC), Ministry of Economy

Trade and Industry (METI) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT). As with any major policy issue in Japan, there is also a myriad of other government bodies that perform certain administrative or consultative roles. In the case of nuclear energy and safety, these include the Ministry of Foreign Affairs, the Ministry of Environment, the Ministry of Internal Affairs and Communications, the Ministry of Health, Labour and Welfare, the Ministry of Agriculture, Forestry and Fisheries and the Ministry of Land, Infrastructure and Transport.

The JAEC, which is part of the Cabinet Office, was established in January 1956, in accordance with the Atomic Energy Basic Law of December 1955. The Commission consists of five Commissioners, appointed by the prime minister for three-year terms, and a Secretariat. The JAEC performs an overarching policy development and advisory role. Its key mechanism for carrying out this role is its long-term plans, which are released roughly every five years. These plans provide strategic and budgetary guidance to METI, MEXT and the other policy implementation bodies, in relation to the promotion of research, development and utilisation of nuclear energy, including issues concerning the closed nuclear fuel cycle.

As the name suggests, the primary role of the NSC is to ensure and enhance safety in the utilisation of nuclear energy and the use of nuclear fuels and materials. It does so in close coordination with METI's Nuclear and Industrial Safety Agency. The NSC, which was established in 1978, mirrors the structure, location and status of the JAEC. METI, via its Agency for Natural Resources and Energy, has regulatory control over Japan's electric utilities, and in turn over the management and roll-out of conventional light water reactors (LWRs). In this sense, METI has the responsibility of ensuring the country's LWRs play their role in providing a stable and efficient supply of energy. METI also has direct regulatory responsibility over refining, enrichment, fabrication, reprocessing and waste disposal.

Within the MEXT sits the Japan Atomic Energy Agency (JAEA), which is the owner and operator of the Joyo experimental FBR and Monju prototype FBR. Despite this government ownership, a large part of the initial costs of Monju's construction was collected from the private utilities. Also, going forward, the central government has established a cost-sharing arrangement for the construction of the post-Monju demonstration reactor, in that the utilities will have to contribute an amount equivalent to the cost of a commercial LWR (Suzuki 2009: 72).

In contrast to Monju, the Rokkasho reprocessing plant is completely a private sector concern, albeit one brought about by the administrative guidance of the government in the late 1970s. Its owner, Japan Nuclear Fuel Limited (JNFL), involves numerous shareholders, but the main ones are the nine major electric utilities and the Japan Atomic Power Company (which in itself is controlled by the nine major electric utilities). With the gradual introduction of a deregulated electricity supply market in Japan from 2003 onwards, it was decided by the Agency for Natural Resources and Energy that the utilities could not afford the high economic risks of reprocessing in such a competitive market place. For this reason, a special fund, financed by charges on all electricity transmission and retail electricity, was established to cover the costs of the reprocessing plant's construction, operation and decommissioning (Katsuta and Suzuki 2006: 12).

The financial beneficiaries of Japan's nuclear power strategies include the private sector firms directly involved in the ownership and operation of reactors, namely the major electric utilities, and the companies involved in the production and servicing of nuclear technology, such as Toshiba, Mitsubishi Heavy Industries and Hitachi. However, major stakeholders also include the prefectural and municipal governments involved in hosting nuclear facilities. The key prefectural governments in this regard are those of Aomori, Fukushima and Niigata, which together account for approximately 60 per cent of Japan's nuclear facilities (Pickett 2002: 1351). They are both major beneficiaries and major decision makers, at least in the context of siting approvals. As scholar, and now commissioner within the JAEC, Tatsujiro Suzuki points out, local governments and communities that agree to host nuclear facilities are rewarded with annual payments in the billions of yen from the central government, and significant tax revenue streams from the nuclear facilities (Suzuki 2009: 73).

Japan's conventional nuclear power developments and strategies

In 1954, roughly nine years after it became the first, and still only, victim of atomic bombings, and less than six months after the US government began promoting the use of nuclear power for civilian purposes, Japan commenced its own nuclear power research programme. Following a number of legislative, administrative and experimental developments from the mid-1950s through to the mid-1960s, which provided the platform for the government's nuclear power strategies, Japan commenced the realisation of its commercial nuclear power programme in 1966. This initial step into the commercialisation of nuclear power involved bringing into full operation the Tokai-1 reactor, a reactor developed with the use of imported technology from the UK. Despite this initial UK connection, US reactor technology became the mainstay of Japan's nuclear power programme from the late 1960s onwards. While the early development of commercial nuclear reactors in Japan continued to depend on imported technology and licensing agreements, essentially from two US companies, Westinghouse and General Electric, by the late 1970s Japanese companies such as Hitachi, Toshiba and Mitsubishi Heavy Industries had established a solid base in terms of domestic nuclear power production and know-how (Low 1999: 71–76; World Nuclear Association 2007). In recent times, these Japanese companies have been part of the consolidation in the global nuclear power industry. Hitachi and General Electric have formed a joint venture, Toshiba has acquired Westinghouse from British Nuclear Fuels Limited (BNFL) and Mitsubishi Heavy Industries now collaborates with French company Areva.

During the 1970s, 1980s and 1990s, there was steady growth in the number of nuclear reactors in Japan, at an average rate of about 1.5 per year. By the end of the 1970s, Japan had 20 reactors in operation; by the end of the 1980s, 36; and by the end of the 1990s, 51 (World Nuclear Association 2007). As a result, as Japan's economy matured, nuclear power's percentage contribution to the nation's electricity generation also grew significantly. For example, according to Johnston (2005), while nuclear power only accounted for about 17 per cent of electricity generation in 1980, by 2004 it accounted for almost 35 per cent. More recently, due primarily to a number of temporary reactor shutdowns, mainly involving the Tokyo Electric Power Company (TEPCO), this percentage has been closer to 30. While Japan's ranking among nuclear powered countries in terms of number of reactors in operation by the end of the 1990s placed it third after the USA with 103 reactors, and France with 59, its ranking in terms of dependency on nuclear generated electricity was well down the list. Not surprisingly, this is because many smaller countries, in terms of population and economic activity, such as Sweden, Belgium and South Korea, among others, are able to meet a larger portion of their electricity needs with a relatively small number of reactors.

In 1990, Japan's nuclear power plant programme became part of the government's strategy for addressing the newly recognised problem of climate change (via the so-called Action Plan to Arrest Global Warming). It was also around this time that the government, as part of its Long-Term Prospect for Energy Demand and Consumption, estimated that by 2010 nuclear power would be generating 2.6 times as much energy in Japan as it was in 1988 (Fukumoto 1992: 19). In a similar optimistic fashion, the government's 1994 Long-Term Programme for Research, Development and Utilisation of Nuclear Energy estimated that by 2030 Japan's nuclear power output would be 100 GW. In reality what has eventuated since the start of the twenty-first century is a significant slowing in the momentum of Japan's nuclear power plant roll-out compared with previous decades. The government's annual Electric Power Supply Plans over the course of 2000 through to 2006 reveal a series of construction postponements across at least a dozen planned reactors, and the abandonment of construction plans in the case of two other reactors. As an example, as of early 2006, the commencement date for the construction of Tohoku Electric's Namie Odaka reactor had been postponed more than 20 times (Katsuta 2004; Nishio 2006).

Nonetheless, as of August 2009, there were 53 commercial nuclear reactors in operation (in 2006 there were 55), 2 under construction, 13 planned and 1 proposed (World Nuclear Association 2009b). And despite the above-mentioned challenges, under the central government's carbon reduction action plan, unveiled in July 2008, which aims for 60–80 per cent cuts in GHG emissions by 2050, plans were outlined for the construction of nine new nuclear reactors by 2017 (*Jiji Press English News Service* 2008a). In June 2009, in METI's nuclear power promotion policy statement, this target for nine new reactors was extended to 2018, with a 2020 target for nuclear power accounting for 40 per cent of electricity supply. This pressure for the short-term roll-out of new nuclear reactors was only intensified via a pledge by the then Democratic Party Prime Minister, Yukio Hatoyama, who stated in September 2009 that under his leadership Japan will aim by 2020 to reduce GHG emissions by 25 per cent, compared with 1990 levels (Ajima 2009). While nuclear power currently accounts for about 30 to 35 per cent of electricity generation, according to the JAEA, by 2100 the government plans to rely on nuclear power for 53 per cent of the country's electricity (Arita 2008). If one takes into consideration the more aggressive GHG emission reduction targets being touted by Japan's recent political leaders, it is possible that the Japanese may also be raising its above-mentioned end-of-the-century nuclear power capacity targets.

The central government is clearly firm in its overall commitment to nuclear power. The question is whether the private sector electric utilities are up to the task of carrying out such huge capital expenditure in an increasingly deregulated and competitive electricity market, and whether the general public is willing to support the central government's policies in the wake of several nuclear facility accidents caused by mismanagement, incompetence, technical faults and larger than expected seismic activity near nuclear power plants. These accidents include the sodium coolant fire at the Monju prototype FBR in 1995, which led to its indefinite shutdown; a fire and explosion at the Tokaimura nuclear fuel reprocessing plant in 1997, which exposed dozens of workers to high radiation levels; a criticality accident at the Tokaimura uranium conversion plant in 1999, which led to the death of two workers; the rupturing of a pipe carrying superheated steam at the Mihama nuclear power plant in 2004, which led to the death of five workers; and an earthquake near the Kashiwazaki-kariwa nuclear power plant in 2007, the largest power plant in the world, which among other things led to a fire, the leakage of radioactive water into the ocean, the shutdown of reactors, and a comprehensive reassessment of reactor safety and resilience in the context of their vulnerability to earthquake damage.

Japan's commitment to a closed nuclear fuel cycle

A once-through nuclear fuel cycle involves a front end and a back end. At the front end are the mining and milling, conversion, enrichment and fuel fabrication. At the back end of the cycle are temporary storage, reprocessing, recycling and waste disposal. To close this cycle, or essentially create a virtual cycle of self-sufficiency, two avenues can be taken. A LWR cycle can be established by fabricating mixed uranium–plutonium oxide (MOX) from the reprocessed spent fuel, which in turn can be used as a fuel in the LWRs. A second avenue is a FBR cycle, which involves using the fabricated MOX as fuel, but in addition, generating additional fuel via the FBRs.

While the development and expansion of commercial LWRs in Japan has faced its own challenges, the realisation of the Japanese government's ultimate energy self-sufficiency 'dream', a closed nuclear fuel cycle, has involved an even more drawn out and bumpier path of experimentation, delays, cost blowouts, shutdowns and fervent grassroots resistance. At the same time, however, the seemingly unbroken long-term, official commitment of the central government to the achievement of a closed nuclear fuel cycle is indicative of just how important the government and many of its advisors believe, or at least, appear to believe, this source of energy is to the country's energy and environmental security. Also, it could be argued that this dogged commitment is indicative of the blind faith that many generations of Japanese technocrats and rubber-stamping, disinterested politicians appear to have had in a closed nuclear fuel cycle. As demonstrated below, the cost blowouts and delays associated with the FBR and reprocessing elements of the closed nuclear fuel cycle provide little, if any, economic logic for such a commitment.

This is not to say there has not been disagreement behind 'closed doors' within government itself about the best course of action concerning certain elements of the country's nuclear power strategies. Even within METI, there has apparently been significant division of opinion in relation to the pursuit of the closed nuclear fuel cycle. For example, Tetsunari Iida, Executive Director of the Institute for Sustainable Energy Policies, claims that in recent years within the ranks of METI there has been a significant division of opinion in relation to the viability of the Rokkasho reprocessing facility. Iida claims that within METI there are essentially two groups of bureaucrats, one group that he describes as the more 'economically' minded, and another which is more 'technologically' minded, or at least has a greater belief in what can be achieved technologically. The 'economically minded people', as Iida puts it, who are also more upwardly mobile within the ranks, are against the promotion of the Rokkasho facility and waste reprocessing in general, on the basis that it is too expensive compared with the 'once-through' option of long-term waste storage. On the other hand, the 'technologically minded people' support Rokkasho and nuclear waste reprocessing. Iida also argues that a similar division, based around those who are more economically focused, and those who are more technologically focused, exists within the country's largest electric utility, TEPCO (Iida 2007). Walker (2006: 751) and Takubo (2008: 81) also highlight this division of bureaucratic opinion about the wisdom of proceeding with the Rokkasho reprocessing plant. The debate apparently stemmed from calculations conducted by the government during the 1990s, which concluded that reprocessing would be more expensive than the once-through approach.

For Japan to achieve its so-called closed nuclear fuel cycle, or in effect, a nuclear power system that is self-sufficient in terms of the production of nuclear fuel, the reprocessing of spent fuel, the use of reprocessed spent fuel and the domestic disposal of high-level nuclear waste that cannot be recycled, ultimately there are four key elements of the government's overall strategy that must be realised. These are: (i) a commercial FBR programme; (ii) large-scale domestic reprocessing of spent nuclear fuel; (iii) the use of MOX in both LWRs and commercial FBRs; and (iv) a long-term solution for the storage/disposal of high-level radioactive waste (HLW). As of November 2009, except for recent trials of MOX use at one conventional LWR, the implementation or full operation of any of these essential elements of the closed nuclear fuel cycle were yet to be achieved. It is also recognised that uranium enrichment and MOX fuel fabrication facilities are essential to such a cycle; however, the technical and political complexities and challenges of the four elements mentioned above are considered far more significant, and are the focus of the following sections of discussion.

Nuclear waste reprocessing: ongoing foreign dependence and multiple delays at the domestic level

An important element of Japan's envisaged closed nuclear fuel cycle is the establishment of domestic reprocessing facilities capable of servicing the majority of the nation's nuclear power industry. Until now the vast majority of Japan's nuclear waste reprocessing has been done overseas, in either France, by COGEMA (now part of Areva), or in the UK, by BNFL. From 1969 through to 1990, there were over 160 shipments, about 3,000 tonnes, of nuclear waste from Japan to these destinations. Since the early 1990s there have been shipments back from either France or the UK, one of recovered plutonium in 1992, two of MOX in 1999 and 2001, and 12 of reprocessed, vitrified high-level waste from 1995 through to 2007. While another MOX shipment from France arrived in Japan in May 2009, all future shipments of recycled waste, nine in all, are expected to come from the UK. Since the exportation of waste for reprocessing ended in 1990, Japan's spent nuclear fuel has been stored domestically, mainly at the reactor plants themselves, but since 1999 this has been occurring increasingly at the high-level waste interim storage facility at Rokkasho, Aomori Prefecture. This is in addition to the thousands of drums of low-level waste that have been stored permanently in a large pit in the Rokkasho facility since the early days of the site's development (Hills 1993; Hollingworth 2007; Japan Nuclear Cycle Development Institute 2007; World Nuclear Association 2007).

At the domestic level, actual reprocessing commenced on a relatively small scale in Tokaimura, Ibaraki Prefecture in 1977, at a facility run by the then

Japan Nuclear Cycle Development Institute (JNC). This plant has had the capacity to reprocess about 90 tonnes per year, or about 10 per cent of the nuclear waste derived from Japan's LWRs. However, its average annual operational output has only ever been less than half this nominal potential, about 40 tonnes per year. The government has indicated that it plans to dismantle the Tokai reprocessing plant by 2010. It will not be until the Rokkasho facility is in full operation that the vast majority of reprocessing is achieved at the domestic level (Sawai 2003; Katsuta and Suzuki 2006: 5).

The Rokkasho site was chosen in 1985. Construction on the various elements of the facility commenced at different times between 1988 and 1993. These various elements include an enrichment plant, a low-level radioactive waste storage centre, a (HLW) storage centre and a reprocessing plant. Applications for a MOX fabrication plant at Rokkasho were only submitted in 2005. As mentioned above, the Rokkasho facility is run by JNFL, the shareholders of which are Japan's 10 major electric utilities, along with 77 other companies. In terms of operational start dates, the Uranium Enrichment Facility and the Low-Level Radioactive Waste Storage Centre commenced operations in 1992, and the High-Level Radioactive Waste Storage Centre in 1995. However, while it was initially expected that the site's reprocessing plant would be up and running by the mid- to late 1990s, a series of delays prevented even active testing from commencing until 2006. Furthermore, since the commencement of final testing, there have been a total of 17 delays to the expected operational start date. In August 2009, JNFL announced that the completion of testing at Rokkasho would not occur until at least October 2010. Compared to the original schedule, this represents a cumulative delay of 13 years. The latest delays relate to problems with the vitrification facility, that is, the mixing of glass with highly radioactive waste, a critical process for storage purposes (Sawai 2009). It is expected that Rokkasho's MOX fabrication plant will begin operations by 2012.

According to JNFL, Rokkasho's reprocessing plant will have a maximum annual capacity of 800 tonnes, which is enough to service the needs of 40 1000 MW-class reactors, or roughly 80 per cent of Japan's current annual spent fuel generation. This of course means that at least 20 per cent of Japan's spent fuel will either be simply stored domestically, or be sent overseas for recycling. In the context of the many delays in the start-up of the Rokkasho reprocessing facility, and the fact that at a cost of approximately US$21 billion it is the world's most expensive nuclear facility, there is no doubt there will be much interest and scrutinising in relation to its performance once it is fully operational (Donnelly 1993: 194; Sawai 2003; Japan Nuclear Fuel Limited 2007; *Kyodo News* 2007; Sawai, 2007).

Because in the short term the reprocessing of spent fuel at Rokkasho is considered essential in terms of freeing up storage capacity at LWRs, the many years of delays have forced the utilities to look at establishing interim alternatives, in the form of away-from-reactor spent fuel storage facilities. This led to TEPCO's application for the building of such a facility in Mutsu City, Aomori Prefecture, which was approved in 2004. This 5,000 tonne capacity, 50-year facility is expected to be operational sometime during 2010. However, this only represents an interim solution to a small part of the problem. The ability to successfully site other such facilities, however, is uncertain, especially because of local government resistance to their prefectures being used as spent fuel dumping grounds. As Katsuta and Suzuki (2006: 21) explain, there are many variables, and depending on how these variables play out, it may be best that Japan actually delays its reprocessing of spent fuel until at least 2015, if not 2025, in order to avoid the further stockpiling of separated plutonium. A key factor is whether Japan's existing stockpile of separated plutonium will be effectively utilised as MOX in LWRs and a restarted Monju prototype FBR.

The use of MOX at conventional nuclear reactors: a 'plan B' with its own history of scandals and delays

A second key element of Japan's closed nuclear fuel cycle is the domestic production and use of MOX, otherwise known as the 'pluthermal' (short for plutonium thermal) programme. While the yet-to-be constructed MOX fabrication plant at Rokkasho will be the centrepiece of MOX production in Japan, as part of the active tests of the reprocessing plant during 2006 and 2007, it was expected that a total of 7 tonnes of MOX fuel would be produced. Otherwise, until the fabrication plant is operational, Japan will continue to import MOX from Europe. On the usage side, the Japanese government's original plan was for MOX to be primarily a fuel for the FBR programme. However, due to the 1995 Monju prototype FBR accident and shutdown, since 1997 the government's MOX policy has focused on the introduction of this fuel to between 16 and 18 of the country's privately run LWRs by March 2011.

Another factor in this shift in the MOX policy was the decision to abandon the advanced thermal reactor (ATR) programme, and in turn decommission the country's only ATR at Tsuruga, Fukui Prefecture. ATRs, while able to use MOX as a fuel, are unable to produce more fuel than they consume, in the way that FBRs are able to do. Essentially, the ATR programme was considered too costly to continue (Pollack 1995; Johnston 2005). In April 2008, however, METI approved the construction of a 1.383 MW advanced boiling water reactor in the town of Oma, Aomori Prefecture. This commercial reactor will be fuelled purely with MOX, and in this sense will be a world first (*Jiji Press English News Service* 2008b; Sawai 2008).

Despite the government's decade-long focus, it was only as recently as early November 2009 that the first trial operations of MOX use commenced at a conventional LWR in Japan. This occurred at the No. 3 reactor of Kyushu

Electric Power Co.'s Genkai nuclear power plant. Other than Kyushu Electric, there are five other electric utilities with all of the necessary central, prefectural and municipal government approvals to use MOX fuel, these being Shikoku Electric Power Co., Chubu Electric Power Co., Chugoku Electric Power Co., Kansai Electric Power Co. (CEPCO) and Hokkaido Electric Power Co. Four other electric power companies are still in the process of obtaining local government approval, one of these being Japan's largest, TEPCO (Ban 2009). While CEPCO and TEPCO both previously had in place approval at all governmental levels for the use of MOX at four plants (two in each case), these plans suffered embarrassing setbacks. In the case of CEPCO, after receiving all of the necessary approvals by 1999, it was discovered that in relation to its MOX fuel that arrived in Japan in the same year from the UK, BNFL workers had skipped required quality control tests, and the data were falsified. As a result, the fuel was sent back, and CEPCO's local government consent was suspended.

A further blow for CEPCO, at least in terms of the extent of local government and public distrust surrounding its MOX plans, came in the form of the above-mentioned August 2004 accident at its Mihama-3 reactor, in Fukui Prefecture. A pipe carrying superheated steam ruptured, which led to the death of five workers and injuries to six others. The pipe had worn thin and had not been properly maintained or even checked since 1976. This was another case, in a growing list, of incompetence and poor maintenance standards within Japan's nuclear power industry. In the case of TEPCO, by 1998 it had received all of the necessary layers of governmental approval. However, in 2001 prefectural approval was rejected after a local referendum in Kariwa Village, and again in 2002 when it was revealed that the utility had falsified its voluntary inspection reports of damage and repairs at three of its plants between 1986 and 2001 (Nakamura 2002; Japan Electric Power Information Centre 2007: 34–35; Katsuta and Suzuki 2007). An additional more recent blow to the roll-out of MOX use was the announcement in June 2009 by the Federation of Electric Power Companies of Japan, which asked member companies to rethink their plans for MOX use on the basis of current deadlines (*Japan Times Online* 2009). Clearly, the lack of consensus or confidence about the short-term introduction of MOX does not only exist within the public, but also within the industry itself.

The development of fast breeder reactors: big plans, big expenses, but stalled progress

Japan's official policies on the closed nuclear fuel cycle, and in particular its clear commitment to the development of FBRs and reprocessing facilities, go back at least to the 1956 Long-Term Plan of the JAEC. In this report, the government set out the basic steps it intended to follow in the development of FBRs. The first step would involve the development of an experimental reactor, the second, prototype reactor development, the third, demonstration reactor displays, and the fourth, commercialisation of FBRs. The first of these steps in FBR development came to fruition in April 1977 when the Joyo (meaning eternal light) experimental FBR attained criticality, a sustained chain reaction. Over time, the output of Joyo has been increased from an initial 50 MWt in 1978 to 160 MWt by 2003 (*Japan Times Online* 2003). Throughout this period, Joyo operated without major incident. This sodium-cooled FBR, located in Oarai, Ibaraki Prefecture, provided the technological basis for the second stage of FBR development, that is, the prototype Monju reactor (named, some may say ironically, after the Buddhist divinity for wisdom). Construction on Monju commenced in October 1985 in Tsuruga, Fukui Prefecture, and was completed in April 1991. One media report in 1993 stated that from the time concrete plans were first discussed in 1968 to build a prototype FBR, through to actual construction, the cost increased 26 times to a final cost of roughly 600 billion yen (Hills 1993; Pollack 1995). In April 1994, Monju went critical for the first time, and in August 1995 it started to generate electricity. However, in December 1995, when Monju was still in its testing phase, it was yet to operate above 40 per cent capacity, and yet to put any electricity into the main grid, between 2 and 3 tonnes of highly volatile liquid sodium leaked from a secondary cooling system, causing a fire. While the accident did not involve any radioactive leaks and did not lead to any injuries, it did reveal a design fault, and brought about the shutting down of the reactor for an indefinite period. Worse still, the operators of the plant failed to follow a number of required procedures immediately after the accident, attempted to cover up the accident by concealing video footage which showed the extent of damage, and submitted a falsified report to the central government (Editor 1995; Low 1999: 79; *Japan Times Online* 2004, 2005b). Clearly, the wisdom of the plant operators did not live up to the reactor's name.

In 1997, only two years after the Monju accident, the JAEC announced that the government should proceed with FBR development and that it considered FBRs to be a strong energy option for the future of Japan. This was followed in 1999 with the commencement of a feasibility study, by the then Japan Nuclear Cycle Development Institute (JNC) and private utilities, into the commercialisation of FBRs (Ban 2006). In a 2001 report, 'Promising Candidate-Concepts for Commercialisation', the government outlined the 40 FBR concepts that were under consideration. Then, in March 2006, the newly established JAEA[1] announced a blueprint for the FBR that will succeed the prototype Monju reactor, that is, a demonstration reactor to be ('creatively') named 'Post-Monju'. This will represent the third step in the overall process of FBR development in Japan. While it is envisaged that the Post-Monju reactor will be similar to Monju in that it will utilise a sodium-based cooling system and MOX fuel, it is expected that the new reactor will be about one-sixth the physical size of Monju, but produce about five times as much output. The JAEA stated that by 2015 it will present a detailed plan of this third stage in the FBR development process, which it expects will come to fruition by about 2030 (*Japan Times Online* 2005c, 2006a).

In the meantime, the government's firm official commitment to FBR development has also been reflected in its efforts to restart operations at the mothballed Monju reactor. The first significant step in this endeavour occurred in June 2001 when the then JNC submitted an application for modification work on the prototype FBR. In particular, and as no great surprise, it was indicated that this modification would be aimed at overcoming any chance of a sodium leak accident in the future. Following approval from the relevant central government authorities in January 2004, and approval from the Fukui Prefectural government in February 2005, modification work commenced in September 2005. In 2007, the JAEA had planned to complete the modification work, and then after carrying out tests on the reactor as a whole, restart Monju by May 2008. As of November 2009, the JAEA's target date for restarting Monju had been extended to February 2010 (Citizens' Nuclear Information Network 2009). The most recent delays related to checks on sodium detection equipment and the wait for new fuel supplies.

In the meantime, billions of yen are being spent each year simply maintaining the plant. If all goes to plan from this point on, which based on past experience with the Monju plant seems unlikely, commercialisation of FBRs in Japan, as previously noted, is slated to come into being by 2050 (Japan Nuclear Cycle Development Institute 2007; *Japan Times Online* 2005a, 2006a; *Nuke Info Tokyo* 2005; Ban 2007). From that point on, according to METI, it is expected that there will be a gradual roll-out of commercial FBRs (along with a gradual decommissioning of conventional LWRs), to the extent that FBRs will account for approximately 40 GWe of installed electricity generation capacity by 2100, roughly 70 per cent of Japan's expected overall electricity generation capacity from nuclear power at that time (Nuclear Energy Policy Planning Division 2006).

Long-term storage and disposal of high-level nuclear waste: 'not in my back yard!'

The final key element of Japan's closed nuclear fuel cycle to be examined is that concerning the long-term storage and disposal of HLW. Irrespective of the reprocessing of spent fuel, as part of the closed nuclear fuel cycle there remains a significant amount of HLW that must be stored for 30–50 years for cooling, and then disposed of, usually through underground burial. The government framework for such handling of HLW was established in 2000 with the promulgation of the Specified Radioactive Waste Final Disposal Act, the adoption of the Specified Radioactive Waste Final Disposal Plan, and the establishment by the private sector of the Nuclear Waste Management Organisation of Japan (NUMO). 'The

Final Disposal Plan mandates the following four steps: selection of preliminary areas for investigation following a review of the scientific literature; selection of areas for detailed investigation within the period from 2008 to 2012; selection of a site for repository construction between 2023 and 2027; and start-up of operation between 2033 and 2037' (Japan Electric Power Information Centre 2007: 35).

Since 2002, NUMO has been running an open solicitation process for candidate disposal sites. The process involves a number of stages, the first of which requires a local government to accept a document study, that is, the screening of academic papers or archived documents to determine whether a site is fit for waste storage. For simply accepting to proceed with this first stage (but without any obligation to proceed beyond it), local governments were offered a subsidy of 210 million yen per year. In 2006, due to NUMO's failure to enlist any official candidate sites, the subsidy was increased to one billion yen. The second and third stages involve a rough outline study, and then a detailed study, each with increasing subsidies.

There have been occasions since 2002 when some local governments have indicated their interest in applying for the first-stage document study, but these potential applicants have been forced to withdraw their interest due to opposition, especially from neighbouring local governments. As of September 2007, there were still no official candidates, not even for the document study, and this led the Agency for Natural Resources and Energy to propose an additional element to the process, which is the submission of applications by the central government to local governments seeking their agreement for studies. The central government's aim is to have a disposal site up and running within ten years of 2028 (*Japan Times Online* 2006b; *Nuke Info Tokyo* 2007a, 2007b).

Key drivers of Japan's commitment to nuclear power

The way one explains the drivers for Japan's commitment to nuclear power can vary significantly. This variance can depend on whether one accepts at face value the official line of reasoning presented by Japan's key policy-making bodies, or whether one incorporates or places greater weight on the independent, less optimistic and often more critical, cynical or even conspiratorial observations of various commentators, such as scholars, anti-nuclear lobby groups or journalists. The way one explains Japan's commitment can also depend on whether one considers the nuclear power programme in its entirety, or in the context of its specific elements. In a broad strategic sense most of these specific elements have been part of the government's nuclear power strategies since the JAEC produced its first and second Long-Term Plans in 1956 and 1961 (Pickett 2002: 1338). However, to some extent the government's reasoning for certain elements of the nuclear power programme, such as FBRs, MOX and domestic commercial reprocessing, has appeared to evolve over time as relevant domestic and international factors have changed, and in particular as the expected implementation timeframes of different elements have changed, or more specifically, have been delayed. The expected commercialisation of FBRs, for example, changed from a start date of 1970 in the 1961 Long-Term Plan to a start date of 2050 in the 2005 Long-Term Plan (Suzuki 2009: 70). And when originally planned, reprocessing was expected to produce a net financial gain, whereas by 1981 the government realised this would not be the case. Also, it was not until 1997 that the Japanese government announced its plan to start using MOX fuel in LWRs by 2010, a decision driven by the 1995 shutdown of the Monju prototype FBR (Takubo 2008: 75, 84).

Central to the Japanese government's commitment to nuclear power is the issue of energy security. Japan is in no way unique in this sense. Energy security has also driven other countries to go nuclear too. Yet, compared with other rich countries, concerns about energy security in Japan certainly carry a great deal of historical weight. Japan was acutely aware of its need to secure stable foreign supplies of energy from the time of its early industrialisation in the first half of the twentieth century, but in particular during the time of its heavy industrialisation during the 1930s. The first real demonstration of Japan's vulnerability to any external threats to its energy security came in the form of the 1941 US oil embargo, which was one of the main triggers for Japan's military aggression across the Asia-Pacific from late 1941 onwards.

As an energy resource-poor country, Japan has always taken this issue seriously and securing energy supplies has been the primary goal of Japan's nuclear power strategies since their initial development in the mid-1950s. The first oil crisis in 1973–74 only highlighted the urgency to find alternatives. At the time, oil accounted for 77 per cent of the primary energy needs in Japan; virtually all of Japan's oil was imported, roughly 78 per cent of this imported oil came from the geopolitically unstable Middle East, and oil-fired power plants accounted for 66 per cent of Japan's electricity supply (Miki 2006; World Nuclear Association 2009a). Diversifying its energy sources became critical for the country's survival. This led to an aggressive roll-out of nuclear power plants in Japan. Nuclear power, and hence the use of imported uranium from politically stable countries, such as Australia and Canada, was part of a diversification strategy from the mid-1970s onwards in the context of both the types of energy resources and the location of foreign energy resources.

Interestingly, while Japan has been successful in dramatically reducing its dependence on oil for its primary energy needs since the 1970s, now down to less than 50 per cent, it has been unable to shake its dependence on the Middle East for the vast majority of its oil imports. In fact, as of 2008, Japan was importing just over 90 per cent of its oil from the Middle East, which in terms of the region's percentage contribution to Japan's oil imports is actually a higher level of dependence than was the case in 1973. In this sense, Japan still remains extremely vulnerable to global oil supply disruptions, and relative to the oil sources of other major economies, Japan stands out as being one of the most vulnerable to any such disruptions occurring in the Middle East (Choi 2009: 10). Oil, however, despite its importance, is only one element of Japan's energy security challenges. Within the context of fossil fuels, Japan is also dependent almost entirely on imports of coal and natural gas, which are both extremely important in the context of electricity generation. Today, coal accounts for roughly 25 per cent of Japan's electricity generation, while gas accounts for roughly 24 per cent (Richardson 2009). The extent of this foreign dependence on imports is further demonstrated by the fact that among the major industrialised countries of the world, Japan has the lowest level of energy self-sufficiency.

In the context of energy security, another issue of concern, especially for a country like Japan, is the inevitable global depletion of critical fossil fuel resources, in particular, reserves of oil and gas. So-called 'peak oil' and 'peak gas' is expected to occur sometime this century. Even the most optimistic forecasts of peak oil, which are around the 2030–40 mark, represent the beginning of an extremely challenging, and some would say catastrophic, adjustment phase for what is still a heavily oil-dependent global economy. This in turn leads one to ask how a country like Japan, with no domestic oil supplies (other than stockpiles), is going to manage this global energy transition, especially in the decades subsequent to the peak oil point, as oil becomes increasingly scarce and increasingly expensive, and as demand for oil continues to rapidly increase from the economic activity of countries such as China and India, who for some years now have been major net importers of oil. Peak gas is expected to occur in the second half the twenty-first century, but again, based on Japan's near complete dependence on gas imports, the importance of establishing viable alternatives in advance of the peak point, and eventual depletion point, is crucial. While global coal supplies are expected to continue much longer into the future, without widespread, large-scale commercialisation of clean coal technology, which could be decades away, it cannot be considered an alternative for gas in the midst of a global effort to hold back GHG-induced climate change.

Nuclear power, especially as electricity becomes increasingly linked to the energy needs of the transport sector via the use of electric and hydrogen fuel cell vehicles, represents a means by which Japan can, to a large degree, free itself of the energy security risks associated with a high dependence on the Middle East for oil imports, and those risks associated with the intensifying competition for increasingly scarce global supplies of oil, and also gas. Furthermore, a closed nuclear fuel cycle, as discussed below, represents, at least in theory, a means by which Japan can overcome to a significant degree its lack of energy self-sufficiency. This will in turn enable Japan to overcome many of the energy vulnerabilities that have threatened the stability of its economic development since the middle of the twentieth century, but most important, will enable it to move forward with a strategy to deal with the inevitable depletion of not only global fossil fuel reserves, but also accessible, high-grade uranium ore reserves, during the twenty-first century.

Since at least the early 1970s, environment security has also been touted by the central government as a key driver or rationale for nuclear power. Nuclear power was seen as a way to reduce the severe air pollution as the result of fossil fuel consumption, which had reached a critical point in the late 1960s and early 1970s. More recently, Japan's nuclear power plant programme has also been driven, or at least justified, by its emerging GHG reduction policies.

The first of these policies was the 1990 Action Plan to Arrest Global Warming. Since then, of course, the targets associated with the 1997 Kyoto Protocol and the soon to arrive post-Kyoto Protocol era have been major drivers. Based on the near zero GHG emissions of nuclear power at an operational level, the Japanese government has been very clear about the importance of existing nuclear power plants in reducing the country's GHG emissions, and the crucial role to be played in future years by an expanded nuclear power plant programme (Nuclear Energy Policy Planning Division 2006).

Yet, neither energy security nor environmental concerns have been behind the drive of the Japanese pursuit of commercial reprocessing of spent fuel. Nor, as mentioned above, have commercial reasons been the main motivator for private sector investment in reprocessing. In fact, according to Takubo (2008: 79), in the 1960s and 1970s Japan's private electric utilities saw investment in reprocessing as a 'nuisance'. What drove the private utilities to eventually commit to reprocessing either domestically or via arrangements with British and French reprocessing companies was the then Science and Technology Agency's threat to withhold permission for the construction of nuclear power plants. Similarly, under current regulations, the utilities that manage any of Japan's LWRs must submit evidence that their spent fuel will be reprocessed before they load any fresh fuel, and are thereby induced by government to maintain their commitment to spent fuel reprocessing (Katsuta and Suzuki 2006: 5).

From a policy-making perspective, in Japan and elsewhere, reprocessing has been seen as a means by which the amount of nuclear waste can be reduced, and thereby the pressure to site and develop waste storage facilities away from power plants also reduced (Walker 2006: 746, 759). In this sense, proponents of reprocessing highlight the particular constraints posed by Japan's geographic structure and geographic size (Oshima 1980: 76). However, according to Takubo (2008: 86), this is a misguided driver, in the sense that the MOX generated from this reprocessing will in itself lead to spent fuel that must be stored while it cools off, and this spent MOX, due to its extreme heat, requires three times as much storage space as spent uranium oxide.

In the context of the massively over budget, long delayed and economically questionable Rokkasho reprocessing plant, various commentators have highlighted the fact that the main driver for the central government's determination to see this plant become fully operational as soon as possible is the 1998 agreement with the host prefectural government of Aomori. On the one hand, the Aomori government does not want to see its prefecture become a permanent dumping ground for spent nuclear fuel, and, on the other, it wishes to secure its much needed future flow of tax revenue from a fully operational Rokkasho reprocessing plant. This agreement essentially forces the central government to guarantee that it will maintain its reprocessing policy. If this guarantee is not fulfilled, then any spent fuel located at Rokkasho must be returned to the original power plants. If this was to occur, then these nuclear power plants would be forced to shut down due to storage capacity constraints, which of course is something the government and utilities cannot afford to see happen (Katsuta and Suzuki 2006: 19; Takubo 2008: 78). In this sense, a key driver for maintaining the direction and momentum of Japan's closed nuclear fuel cycle policies is the political power of local governments and the associated negative political and economic ramifications of backtracking or carrying out a major change to the country's key nuclear power strategies.

Of course, all of the above reasoning, whether it be linked to energy or environmental security, or storage capacity concerns, ignores, or fails to weigh up, the potentially overwhelming health and proliferation risks associated with Japan's nuclear programme. The health risks stem from the fact that this programme involves, among other things, a large number of reactors, and rapidly growing stockpiles of spent fuel, reprocessed nuclear fuel and high-level radioactive nuclear waste located in a seismically unstable, densely populated country; and a privatised nuclear power industry operating in an increasingly deregulated competitive electricity market where cost cutting and managerial incompetence have become commonplace in recent years. When one also considers the risk of terrorist attack, or the potential for the Japanese government to covertly or overtly develop nuclear weapons and in turn dramatically alter the geopolitical environment in the Asia-Pacific, the net benefits of, or drivers behind, Japan's commitment to nuclear power appear to be less clear, or at least much less easily rationalised from broad human security perspectives.

One has to ask, though, can the Japanese government-envisaged energy security benefits of a closed nuclear fuel cycle be justified by any economic logic? Are there sound economic reasons behind the commercial FBR development, commercial reprocessing of spent nuclear fuel and the use of MOX in LWRs? According to McCormack (2007), there appears to be a dearth of such logic. For example, he notes that FBRs are four to five times more expensive as conventional nuclear power reactors, and the process of using MOX in LWRs is several times more expensive than the use of low-enriched uranium (LEU). Even the JAEC has recognised that the reprocessing of spent nuclear fuel was a more expensive process than the once-through approach of waste storage and disposal. To add to this, none of these closed nuclear fuel cycle processes have yet become a reality in Japan on a broad commercial scale, and they are all recognised as carrying a great deal more risk than the conventional once-through fuel cycle. The Japanese government's closed nuclear fuel cycle aspirations, at least in the short to medium term, are not driven by sound economic logic. However, it is hard to determine how the economic logic of commercial reprocessing, MOX fabrication and use, and commercial FBRs will stack up in a post-oil or post-gas world economy.

As suggested above, there are those who view the Japan's nuclear programme, and in particular the closed nuclear fuel cycle, with a significant amount of cynicism and suspicions about the government's nuclear weapons intentions. For example, in a 2009 submission to the Australian Federal government's inquiry into Nuclear Non-Proliferation and Disarmament, Tokyo's Citizens' Nuclear Information Centre stated:

> It would appear unfair to the many people who, however mistakenly, believed a 'closed' nuclear fuel cycle would assure Japan's energy security to assume that they all shared a secret objective of retaining the option of developing nuclear weapons. Equally, however, it would be naïve to assume that the nuclear weapons option played no role in the decision makers' calculations.
>
> (Citizens' Nuclear Information Centre 2009)

Such observations are not without good reason. Since at least 1960, there have been a number of statements by conservative Japanese prime ministers and other prominent politicians, not to mention secret investigations in the late 1960s and again in 1995, which suggest that the Japanese government, or at least some of its key members, regularly weigh up the pros and cons of some day acquiring a nuclear arsenal. This includes comments to this effect by past and present high-ranking Liberal Democratic Party members such as Nobusuke Kishi, Eisako Sato, Yasuhiro Nakasone, Shintaro Ishihara, Tsutomu Hata, Shingo Nishimura, Takeo Fukuda and Shinzo Abe (Campbell and Sunohara 2004; Chanlett-Avery 2009: 6).

Conclusion

Over the last decade and a half the Japanese government and the Japanese semi-government and private organisations involved in the nuclear power industry have faced significant hurdles, especially in attempting to make a closed nuclear fuel cycle a reality for Japan. In many ways, however, these hurdles have been the result of their own incompetent, and many would argue, misguided actions. By venturing into and maintaining a commitment to the development of a closed nuclear fuel cycle, irrespective of an apparent lack of economic logic, the government has created an uneasy existence for nuclear power within the broader Japanese community, and has raised serious questions about its true intentions.

On the one hand, Japan's residential and business sectors expect and require a stable flow of base-load electricity, and nuclear power has a substantial existing and even greater planned future role to play in this regard. On the other hand, many citizens and commentators in and outside Japan are understandably uncomfortable with the direction being taken with the nation's nuclear policies because of past incidents and the perceived technological, financial and safety risks. In recent years, the media have often associated nuclear energy developments in Japan with 'delays', 'technical faults', 'shutdowns', 'cover-ups' and 'cost blowouts'. These terms reflect an industry experiencing serious troubles, not only in image, but also in actual execution of policy and service delivery.

If the ambitious commitments of Japan's central government to the much touted energy and environmental security generating roles of the country's nuclear power industry are to be realised, then the industry itself needs to demonstrate short-term, meaningful breakthroughs and solid, consistent, confidence-boosting progress, especially in terms of effectively managing its spent fuel and nuclear waste storage challenges, and the technical and financial challenges associated with FBR development and commercial reprocessing. In this sense, the events of the next few years will be an important measure of how things will pan out over coming decades for nuclear power in Japan.

That said, clearly no one knows exactly what the future holds for Japan's nuclear power industry. It is worrying, though, that Japan is a country that prides itself on managerial and technical excellence, quality control, customer service and effective long-term planning, but these are the very areas in which the nuclear power industry has often failed to prove itself in recent years. Furthermore, the nuclear path that the central government has led the country down is one that suggests a great deal of future insecurity and uncertainty, especially in terms of the management of plutonium and high-level nuclear waste stockpiles.

Japan's energy and environmental security, and in turn the country's broader economic and human security, are hinging on how the country's nuclear power programme evolves over the coming decades. If Japan's massive budgetary and research and development commitment to nuclear power, especially in the form of the closed nuclear fuel cycle, fails to deliver the energy self-sufficiency and GHG emission-reducing benefits that its pundits have been promoting for some years, the risk is that by the middle of the twenty-first century, or even earlier, Japan will be facing a huge opportunity cost associated with its failure to direct more funds, regulatory measures and research and development into other areas of energy generation that many believe represent a more rational long-term strategy – namely, alternative, renewable energy sources, along with much greater energy efficiency improvements, and generally a movement away from increasingly energy-intensive consumer lifestyles.

In the meantime, while there are some indications of disagreements within and between private sector and governmental circles about elements of the country's closed nuclear fuel cycle strategies, the official line of the central government, as represented by the JAEC, and the two key policy implementing ministries, namely METI and MEXT, continues to be one that represents, at least on the surface, a unanimous commitment to a large-scale, twenty-first century, closed nuclear fuel cycle programme. However, even though this commitment has been maintained, there are still serious concerns that the effective closure of the nuclear fuel cycle, either via MOX use in LWRs or via the commercialisation of FBRs, will for some time yet be little more than a grand pipedream.

Note

1. The Japan Atomic Energy Agency (JAEA) was established on 1 October 2005 through the unification of the Japan Atomic Energy Research Institute and the Japan Nuclear Cycle Development Institute. Until this time the JNC owned and operated the Joyo and Monju FBRs.

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7
Nuclear Energy Development in South Korea

Maeng-Ho Yang and Xu Yi-chong

Introduction

In less than 40 years, South Korea developed one of the most successful nuclear industries in the world. In the 1970s, it launched its nuclear power programme when the size of its economy was merely 7.5 per cent of that in Japan at the time and its GDP per capita was lower than that in North Korea (Maddison 2006: 298–306). Given its low level of development and weak industries, it depended completely on foreign technology and assistance. Westinghouse and other foreign suppliers delivered completed plants with minimal Korean industry input. They designed, manufactured, constructed and eventually operated and managed the first nuclear power plant in South Korea. In barely a decade, Korean companies started participating in construction and the Korean Electric Power Corporation (KEPCO) embarked on an effort to standardise and localise imported technology and develop a Korean model. In two decades, Korean designers worked with the American firm Combustion Engineering (C-E) to develop a Korean model of reactor OPR-1000. By the end of the century, it developed its advanced power reactor APR-1400. By 2010, nuclear power plants were able to meet over 30 per cent of the country's electricity demands.

Nuclear energy development in South Korea is an exemplar of what Peter Evans calls 'efficacious states' that 'combine well-developed, bureaucratic internal organisation with dense public-private ties' (1995: 72). The government from the very beginning was determined to develop a nuclear energy industry as a part of the national economic development strategy, and a strategy to diversify its energy supplies and to meet its rising electricity demand. With this determination, it has developed a set of coherent policies to support targeted industries, introduce advanced science and technology, and invest heavily in research and development (R&D) and in human capital development. Rapid industrialisation required energy and energy development in turn facilitated industrialisation and economic growth. In less than 40 years, South Korea has not only become one of the richest countries in Asia, it is currently making its nuclear power plants new major export items.

Studies have shown a positive correlation between nuclear energy development and national economic development in South Korea (Yoo 2005; Yoo and Jung 2005). Its nuclear energy has achieved a high level of performance and growth without compromising safety. The International Energy Agency (IEA) sees Korea's nuclear energy industry as 'a model for other countries – a commendable achievement, particularly in light of its relative youth' (IEA 2006: 144). The industry has reached its full maturity and covers design, building and operation of nuclear power plants, maintenance services, fuel fabrication and radioactive waste management. There has also been a system that ensures sufficient funding to cover future cost. Indeed, one of the major successes of its nuclear industry is that the cost of nuclear power is quite competitive with other sources of electricity generation. With the democratisation movement in the 1990s, the country particularly built an elaborate and comprehensive regulatory framework to ensure safety. All these could not have been done without an active government's involvement, a national strategy and the close cooperation between the public and private sectors. This chapter explains the way the nuclear industry developed in South Korea.

Background

The government's determination was translated into a set of well-thought-out strategies of introducing technology by importing turnkey projects first, gradually expanding local participation and local components, standardising the technology based on upgraded local design and becoming competitive in the international market. After less than four decades, the nuclear industry in South Korea has not only been able to supply nearly 40 per cent of the country's electricity but also to be competitive with the 'old' nuclear industry players, such as Westinghouse and Areva. This government-fostered development in turn has reshaped the political and economic landscape in the country.

After World War II, Korea was one of the poorest countries in the world and the three-year war in the early 1950s completely destroyed the country's industries and the economy. After the Korean War, the economy went through a decade of reconstruction and a slow recovery with assistance from the USA. In 1962, the government launched a series of economic development plans which allowed the government to allocate its resources and transform the economy. In 1960, the size of the South Korean economy (US$3.89 billion) was half that of the Philippines (US$6.68 billion) while the two countries had a similar size of population. By 2008, the economy in South Korea was more than five times that of the Philippines (US$929 billion versus US$167 billion in 2008), while its population was half of the Philippines (48.6 million versus 90.3 million).

The first three five-year economic development plans (1962–76) proved to be quite successful with a number of developments: the normalisation of relations with Japan in 1965, fiscal and financial reforms in the mid-1960s aimed at maintaining stabilisation of the economy, the Middle East construction boom in the 1970s and the relative free trade environment, based on the General Agreement on Tariffs and Trade (GATT) system, which enabled Korea to gain access to export markets such as the USA while being able to maintain a relatively protected domestic market.

By the 1970s, the Korean economy had established its reputation as one of the Asian tigers with a newly industrialising economy. In the 1960s and 1970s, economic reforms emphasised labour-intensive light manufacturing exporting industries and the development of firms best able to expand export capacity and to acquire and utilise technology. Government-owned banks facilitated this process through their preferential allocation of credit to such firms. This development strategy proved to be highly successful. The average annual growth rate was 8.8 per cent in 1962–71, double that prior to 1962. Per capita income rose from US$82 in 1961 to US$286 in 1971. The industrial structure of the economy changed too, with the share of manufacturing industry increasing from 12 per cent to 20 per cent of GDP and employment in manufacturing industries doubling from 10 per cent to 22.5 per cent of total employment in the same period. Exports increased rapidly from US$41 million in 1961 to US$1,133 million in 1971, representing an average annual growth rate of 39 per cent, and its share of GDP increased from 2.4 per cent to 11.3 per cent (Figure 7.1). The development strategy increased domestic savings and employment, and enabled the economy to benefit from economies of scale in production and technology transfer.

In the early 1970s, the government adopted a strategy promoting its heavy and chemical industry (steel, heavy machinery, automobiles, industrial electronics, shipbuilding, non-ferrous metals and petrochemicals) (1972–79) as its exports of light industrial products had slowed down. The strategy gave a major boost to the growth of the *chaebol*, which radically transformed the industrial and market concentration in South Korea. It had its adverse consequences too: rapid monetary expansion and increased budget deficits, overlapping investments, economic inefficiency, socialisation of bankruptcy risks and increasing corruption cases between politicians and *chaebols*. The two oil crises highlighted economic difficulties and demand for political reform.

Democratisation and economic development interacted in the modernisation of South Korea, as in some other Asian countries: authoritarian regimes controlled the market while economic growth facilitated democratisation in the country. After the assassination of President Park in 1979, the country started moving from the military to a civilian regime and from the authoritarian to a democratic society in the 1980s. The government focused on economic stabilisation and liberalisation (1980–89) by promoting trade, greater opening to foreign investment and greater degree of financial liberalisation, by supporting small- and medium-sized enterprises, enforcing stronger antitrust legislation and adopting structural change towards the development of more technology-based industries. The strategy worked and the success was remarkable. Its GDP jumped from US$111 billion in 1986 to US$558 billion in 1996. In the following decade, the size of the Korean economy doubled again to US$1.05 trillion by 2007. Its GDP per capita ranks number 50 in the world. Its economic development is one of the more successful stories and its nuclear energy development reflects this success.

The economic development could not have happened without sufficient energy supplies, especially modern energy – electricity and heat. Electricity has played a key role in Korea's industrial development. With the merger of three electric utilities in 1961 and the formation of the Korea Electric Company as a joint stock company, the country launched a series of five-year power development programmes to meet the rising demand for electricity and improve the reliability of the power system. Korea Electric Company was reorganised in 1982 into a government-owned utility and was renamed as the Korean Electric Power Corporation (KEPCO). The government controlled 79 per cent of the stakes and the remaining 21 per cent is widely held in the society. KEPCO is a vertically integrated electricity utility that owns and operates 85 per cent of the country's total installed capacity and is the statutory monopoly for the transmission and distribution of electricity.

When the Korean War ended in 1953, the country had a total installed electricity generation capacity of only 127 MW. In less than a decade, the capacity almost tripled to 367 MW in 1961, and then expanded to 2,628 MW by 1971, seven times that in the previous decade, sufficient to meet the country's demand. The total installed capacity then expanded eight times to 21,126 MW by the end of 1991, and then to 77,652 MW by 2009; it had, more than tripled in less than two decades. Electricity consumption per capita reached 8,502 kWh in 2007, on par with the average in OECD countries, three times the world average, and 12 times the average in Asia (Choi et al. 2009; IEA 2009). Unfortunately, South Korea is extremely poor in energy resources endowment. It does not have oil or natural gas reserves at all. Coal was not much of an option either. South Korea had about 4 billion tonnes of coal reserves, all of which were low quality. Its coal production steadily increased from about 13 million tonnes (mt) in 1971 to the peak near 25 mt in 1988–89. It went into a sharp downturn afterwards. By 1993–94, its domestic production met only 12 per cent of the country's demands. Electricity consumed more than 40 per cent of the domestic coal production (IEA 2006: 84). Its energy import dependence rose from about 50 per cent at the end of the 1960s to 75 per cent a decade later, and reached 97 per cent by the 1990s. Without much hydro potential, Korea's electricity was predominantly generated by oil- and coal-fired thermal power generation plants, which all depended on imported resources. A high level of dependence on imported oil and coal made not only the electricity industry but the whole economy vulnerable to international energy markets. The first oil crisis in the early 1970s almost brought the Korean economy to its knees and the need for diversifying energy types and sources was apparent. Fuel diversification nonetheless could not take place over night. When the second oil crisis hit the world, 92 per cent of Korea's electricity was still produced from oil based thermal power plants.

Nuclear power became one option to diversify energy supplies.

Nuclear energy development

Nuclear energy development in South Korea has gone through five stages: (i) preparation (late 1950s to early 1970s); (ii) introduction of turnkey projects (1971–78); (iii) promotion of localisation (1978–87); (iv) self-reliance on its own technology; and (v) competition in the world (1995 onwards). In a short history of three and half decades, South Korea has become one of the major nuclear energy technology holders and successfully bid to win the contract of US$40 billion to build and operate four nuclear power plants in the United Arab Emirates in December 2009.

The interest in nuclear energy began in the late 1950s. South Korea was among the founding countries of the International Atomic Energy Agency (IAEA) in 1957. Its government established an Atomic Energy Commission and the Korean Atomic Energy Research Institute in 1959. In the early 1960s, oil and coal had been the major energy resources and the country depended on these energy imports. Nuclear power was then considered as one of the options to diversify the energy mix to meet rapidly increasing energy demands and to reduce its dependency on foreign energy resources.

In 1962, it imported and installed a US research reactor, TRIGA-MK II. It also reached an agreement with the Americans on arrangements for training numerous Korean scientists, engineers and administrators in the USA. Discussion on introducing the nuclear power plants in Korea was started by organising a committee on nuclear power generation and launching a feasibility study. In 1963, the IAEA issued a consultation report, 'Report of IAEA Mission to Korea', and recommended the introduction of a nuclear power plant with 150 MWe in the early 1970s. Based on this recommendation and other national feasibility study results, the IAEA issued a 'Nuclear Power Plant Survey Report', which was the first report on the national nuclear power generation programme, in 1964. In 1965, the second IAEA expert mission again surveyed and produced the report, 'Siting Aspects of a Nuclear Power Reactor in the Republic of Korea'.

In 1966, the government issued the report titled 'Plans for Long-Term Energy Supply and Nuclear Power Plant Construction', which established the main framework for introducing a nuclear power plant over the five-year period between 1970 and 1974 and selecting plant sites among the possible candidates through a detailed survey. This initial plan was updated

Table 7.1 Electricity generation by sources in South Korea (MW)

	Hydro	Coal	Oil	Gas	Nuclear	Others	Total
2008	5,505	23,705	5,407	17,969	17,716	2,188	72,491
2005	3,883	17,865	4,710	16,447	17,716	1,537	62,258
2000	3,149	14,031	4,866	12,699	13,716		48,451
1995	3,094	7,820	6,119	12,699	13,716		32,184
1990	2,340	3,700	4,815	6,536	8,616		21,021
1985	2,223	3,700	7,348	2,550	7,616		16,137
1980	1,175	750	6,897		2,866		9,391
1975	621	700	3,399		587		4,720
1970	329	537	1,642				2,508

Source: Korean Electric Power Statistics Information System, available at http://epsis.kpx.or.kr/epsis/servlet/epsis/EEFA/EEFAController?cmd=009002, accessed 1 August 2009.

several times, reflecting the increased projections of electricity generation capacity. In 1968, the government formally decided to build two nuclear power plants. Orders were placed in 1970 with Westinghouse for a 600 MWe pressurised water reactor (PWR). After a series of successful contract negotiations by KEPCO, the plant construction and nuclear fuel supply contracts were signed on 24 June 1970 and the groundbreaking ceremony at the Kori site was held on 19 March 1971 with a design capacity 595 MWe Westinghouse type PWR, which started its commercial operation in April 1978, opening up a new era of nuclear power in Korea. In 1976, a second 600 MWe PWR was ordered from Westinghouse.

Since then, nuclear energy development has been made a top priority and has received considerable financial support from the government over the three decades. By 1990, nuclear power reached 8.6 GWe, accounting for 41 per cent of the total installed generation capacity of Korea, the fourth largest proportion in the world behind France, Belgium and Sweden. In 2008, nuclear power accounted for 24.4 per cent of the country's total installed generation capacity and produced 35 per cent of the country's electricity (see Table 7.1).

By 2010, Korea had 20 nuclear power plants in operation with 17.7 GWe net capacity and six units were under construction with a total capacity of 6.5 GWe. The nuclear industry became one of the important components of its economy.

Self-reliance of nuclear technology

From the very beginning, the government made nuclear energy self-reliance its policy. Two oil crises in the 1970s served to confirm the soundness of national judgement on nuclear power deployment in Korea. Until then, the government policy had been 'focused on nuclear R&D institutional building and international cooperation, while on the research and development side, nuclear activities were mainly focused on basic research into radioisotope utilisation and radiation applications in the field of industry, agriculture and medicine on a relatively small scale rather than into nuclear power as an alternative energy source on a large scale' (Park 1992: 725).

At this stage of nuclear development, the government decided to introduce turnkey projects and use foreign contractors to lead the projects so that the Korean engineers and people in the industry could learn. The first two projects were Kori 1 (1969) and Kori 2 (1974) and both were imported turnkey nuclear power plants with Westinghouse reactors, General Electric (GE) supplying turbine generators and Gilbert Associate taking upon the architectural engineering. It also introduced the CANDU reactor from Canada (Wolsung 1). In all three projects, foreign contractors assumed overall responsibility for the construction and operation of the plants. The participation of Korean companies in the construction of nuclear power plants was limited. But the government invested heavily in developing the country's technical capabilities and human capital. By the time the first nuclear power plant, Kori-1, went into commercial operation in 1978, KEPCO, the state-run utility company, and the Korean Atomic Energy Research Institute (KAERI), a government-supported national nuclear R&D institute, started playing a more significant role in introducing and assimilating the imported technology and obtained considerable project management skills.

The next stage of nuclear energy development started in 1978 when the government announced a plan to build 46 nuclear power reactors by 2000 and a change in its strategy by replacing the initial approach of turnkey projects with a 'component approach' to help establish national capabilities. 'Contracts were awarded separately for major components of the plants and several foreign prime contractors were used, thus enabling more domestic industries to participate in the projects' than the previous periods (Park 1992: 726). The objective was to give domestic firms orders worth at least 30 per cent of the total project cost, while still continuing to import the nuclear steam supply system (NSSS) and turbine generators. To facilitate this localisation process, the government created Korea Nuclear Services (KNS) to provide engineering services for all nuclear projects and the nuclear power projects and the Korea Heavy Industries and Construction Company (KHIC) to build nuclear power plants. KHIC was formed by merging the nuclear engineering interests of Hyundai and Daewoo, the engineering conglomerates. KHIC was incorporated as a subsidiary of KEPCO. Six PWRs were ordered between 1978 and 1980 – four from Westinghouse and two from Framatome. In the early 1980s, there was a burst of activity with eight reactors under construction.

Under this framework, the government was in charge of developing a national nuclear strategy and nuclear energy policies; KEPCO was responsible for procurement, commissioning and plant operation; whilst KNS, Hyundai and Daewoo were each assured of a rising share of a market, worth billions of dollars. This was a deliberate policy to foster domestic industrialisation.

As its nuclear energy programme was expanding, South Korea increased its technical cooperation with the IAEA throughout the 1980s. In 1981–88, the total amount of technical assistance from the IAEA to South Korea reached over US$5 million, of which 65 per cent went to nuclear engineering and safety-related projects. 'The most striking feature of the assistance programme is the distribution of recipients' (Islam et al. 1989: 41). That is, even though the group of people representing the largest part of the nuclear industry was affiliated with KEPCO, over 90 per cent of the assistance went to national organisations other than KEPCO, primarily to KAERI and the Korean National Security Council (NSC) to strengthen its regulatory and technical capacity. While KEPCO could get sufficient public and private financial resources to build the country's hardware in the nuclear industry, the 'software' development of regulatory and other human capacities in KAERI and NSC depended on the budget.[1] The IAEA's training programmes, fellowships and technical assistance helped the country build its regulatory capacity.

In the mid-1980s, the Korean government and nuclear organisations adopted an ambitious self-reliance programme, emphasising technology transfer, standardising the technology and developing its own design. In 1987 Korea decided on the CE System 80 steam supply system as the basis of standardisation. Yonggwang (YGN) 3&4 project adopted the joint design and were primarily under the responsibility of domestic contractors: KHIC for supplying nuclear power plant equipment such as NSSS and turbine generators, KAERI for supplying nuclear power design with KEPCO for architectural engineering and the Korea Nuclear Fuel Company (KNFC) for supplying nuclear fuel. Foreign companies were selected as sub-contractors so that the Korean workers could get on-the-job training.

The national target for self-reliance on technical capability in constructing nuclear power plants and fuel cycles was to secure the capability to independently replicate YGN 3&4 (1,000 MWe, PWR) type nuclear power plants excluding some limited areas (Table 7.2). In 1991, the Ministry of Energy and KEPCO issued a white paper which indicated the country's plan for technology localisation.

Korea desired to obtain nuclear supply infrastructure, including NSSS engineering and manufacturing capability. Its overall goal was to achieve 95 per cent self-reliance in nuclear power technologies by 1995.

Using YGN 3&4 as a reference and incorporating selected advanced design features, the nuclear industry developed the Korean Standard Nuclear Power Plant (KSNP) design from February 1989 to April 1991, eventually leading to the construction of the first KSNP, UCN 3&4 and several units including YGN 5&6. Uichin 5&6 were constructed with further improvements.

Table 7.2 Localisation schedule of nuclear power plant technologies (%)

Unit	NSSS (A)	TG[a] (B)	BOP[b] (C)	A + B + C average	Civil engineering	AE[c] and design
Kori 3&4	10	11	35	29	95	37
YGN 1&2	19	30	42	35	95	44
Uljin 1&2	26	40	55	40	95	46
YGN 3&4	63	94	73	73	95	95

Note: [a] TG: turbogenerators; [b] BOP: balance of plant; [c] AE: architectural engineering.
Source: Quoted from Park (1992: 726).

In the mid-1990s, the Korean nuclear industry started advanced reactor development, replicating OPR1000 and improving KSNP to KSNP+ in order to meet evolving technical requirements. The APR-1400 was originally known as the Korean Next-Generation Reactor when work started on the project in 1992. The basic design was completed in 1999. The first two APR-1400 units, Shin Kori 3 &4, were still under construction in 2010, and they were expected to go into operation in 2013 and 2014. APR-1400 is also the type of reactor with which South Korea is trying to capture a large share of the world nuclear reactor market (Table 7.3).

As described above, major factors in the successful development of nuclear energy in Korea, in particular as a developing country, may be divided into four parts, that is, strong government support for nuclear energy, international nuclear buyer's markets due to Three Mile Island unit II accident in 1979 and the Chernobyl accident in 1986, secured qualified and skilful manpower, and extended R& D investment and international cooperation. Government support was effective primarily because 'of the centralised form of Korean political and administrative structure [that] enabled the government to maintain relatively coherent nuclear policies and thus to cope effectively with the rapidly changing domestic and international environment' (Park 1992: 730–731). Nuclear energy development has always been a part of the national economic development. Through its controlling share of KEPCO, the government ensured adequate investment in

Table 7.3 Reactor technology of Korea

	Design life	Electric output	Construction period
OPR1000 (proven technology)	40 years	1,000 MWe	47 months
APR-1400 (evolutionary Generation III)	60 years	1,400 MWe	48 months

the nuclear industry and in the electricity infrastructure so that development and expansion of steel-making, petrochemical and shipbuilding were possible.

Furthermore expansion of nuclear energy enabled Korea to keep energy prices, in particular electricity prices, low compared with other countries, and contributed to strengthening the price competitiveness of export goods as the growth engine of Korean economy. According to the IAEA report released in October 2006, the electricity price was 5 cents/kWh in Korea while it was in the range of 8–16 cents/kWh in other countries. The price was even lower according to the calculation of Korea Hydro and Nuclear Power (KHNP). The average price of electricity of KEPCO was 5.21 cents/kWh (68.3 KRW/kWh) while the price for nuclear power was 2.89 cents/kWh (39 KRW/kWh) (Table 7.4).

Nuclear development became part of the 'virtuous' development cycle in South Korea:

> The success of the nuclear power program provided an ample and stable electricity supply which greatly accelerated the economic development. This accelerated economic development could, in turn, generate the sufficient capital to construct additional NPPs. This virtuous cycle is one of the most valuable lessons from the success of Korean experience that contributed to making Korea one of the advanced industrial countries today.
> (Choi et al. 2009: 5499)

In 2005, the KSNP/KSNP+ was rebranded as OPR-1000 (Optimised Power Reactor) apparently targeted for Asian nuclear markets, particularly Indonesia and Vietnam. Six operating units and four under construction are now designated OPR-1000.

Currently, 20 nuclear power plants are in operation, six under construction and eight at the planning stage in Korea. Nuclear electricity generation provides 40 per cent of total electricity consumption in Korea. Performances of nuclear power plants in Korea are showing excellent capacity factors over 90 per cent, highly comparable with other nuclear advanced countries of the world.

Table 7.4 Cost-competitive energy in Korea

Fuel	**Nuclear**	**Coal**	**Wind**	**Hydro**	**LNG**	**Oil**	**PV solar**
US¢/kWh	2.98	4.10	8.19	9.98	10.96	14.89	49.39
KRW/kWh[a]	39	53.7	107.3	130.7	143.6	195	647

Note: KRW: Korean won; exchange rate at the end of 2008 was 1,310KRW/USD.
Source: KHNP (2009).

Current nuclear energy policies

While concern about energy supplies remains a key motivation for the country to expand its nuclear energy capacity, it is now also motivated by the concerns of climate change. South Korea has witnessed one of the world's highest growth rates of CO_2 emissions, with an average annual growth rate of 4 per cent between 1990 and 2004 (Yoo and Yoo 2009: 86). Its CO_2 emissions per capita is more than double the world's average (10.09 versus 4.38 t CO_2/per capita) and its energy intensity is nearly triple that in Japan (IEA 2009). South Korea has to deal with climate change problems and nuclear energy has been considered one of the best options for the country. Its industry has already mastered the technology to build large and safe nuclear power plants and the country has built a sufficient human capital for its nuclear expansion to cope with high oil prices and global warming. In expanding its nuclear energy programme, the Korean government believes the country can lead in the transition to a low-carbon economy worldwide.

In January 2007, the Ministry of Education, Science and Technology (MEST) adopted the Third Comprehensive Nuclear Energy Promotion Plan (CNEPP) for 2007–11. This plan includes the third five-year National Nuclear R&D Plan with the same timeframe. The CNEPP established the vision that nuclear expansion would be achieved to ensure the country's energy security, protect the environment, improve human welfare and assist science and technology (S&T) development. In 2008, President Lee Myung-bak introduced a new national vision, 'Green growth'. 'Green growth refers to sustainable growth that mitigates greenhouse gas emissions and prevents environmental degradation,' he explained. 'It is also a new national development paradigm that creates new growth engines and jobs through green technology and clean energy' (quoted in O'Donnell 2010: 2).

This is not only a vision; it is a top-down development strategy. The government has made a serious commitment in investing in S&T development so that South Korea will become the leader of green technology in the world. Six policy goals are specified in the CNEPP:

- To secure a nuclear energy supply for a sustainable development.
- To focus on nuclear energy as 'energy together with the public' through an improvement of safety.
- To promote the export of nuclear industry goods by attaining an international competitiveness.
- To improve the public health and quality of life through radiotherapy utilisation.
- To establish the infrastructure for an efficient promotion of nuclear energy.
- To strengthen nuclear diplomacy and international cooperation.

Table 7.5 Investment plan for CNEPP (KRW 100 million)

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**Total**
Government	3,327	3,787	4,101	4,319	4,643	20,177
Industry	800	824	827	825	877	4,180
Total	4,127	4,611	4,928	5,171	5,520	24,357

Source: Ministry of Education, Science and Technology (2007a).

Table 7.6 Investment plan for national R&D programme (KRW 100 million)

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**Total**
Nuclear R&D fund	1,704	1,709	1,729	1,765	1,819	8,726
General budget	461	646	528	484	506	2,625

Source: Ministry of Education, Science and Technology (2007b).

The plan shows that over 80 per cent of the investment in S&T development would come from the government (Table 7.5).

The Third Five-Year Plan for Nuclear Energy R&D (2007–11) outlined by MEST in January 2007 provided a detailed investment plan as shown in Table 7.6. The main objectives of the plan are as follows:

- Development of key future nuclear technologies for securing a nuclear energy supply.
- Attainment of proactive nuclear safety management technology for improving public confidence.
- Concentration on potential 'original technology' development for export.
- Research development to improve public health and to strengthen the foundation for high-technologies.
- Construction of the infrastructure for enhancing nuclear R&D efficiency.

On 11 September 2008, the National Energy Commission that was established in 2007 put forward the First National Energy Basic Plan that provided the direction of the national energy policy until 2030 on the basis of the 3Es – Energy Security, Economic Efficiency and Environmental Protection. The National Energy Basic Plan which covers time span of 20 years will be modified every five years.

One of the five energy goals set out in the Basic Plan is 'Increasing the Supply of Clean Energy'. It proposed that renewable energy sources and nuclear power would account for 11 per cent and 41 per cent, respectively, of the energy mix by 2030. The Ministry of Knowledge and Economy (MKE) published 'The Fourth Basic Plan for Electricity Supply, 2008–2022'

Table 7.7 Prospects of nuclear power capacity, 2030

	1961	1970	1980	1990	2000	2008	2030
Total installed capacity (GWe)	0.367	2.510	9.390	21.02	49.45	72.49	105.20
Installed nuclear capacity (GWe)			0.587	6.7	13.72	17.72	42.72
Total electricity generation (TWh)	1.7	9.2	37	107	262	424	565
Nuclear generation (TWh)			3.5	53	109	151	334

Source: KHNP (2008).

in December 2008. This Plan was modified to reflect changes in policy environments and changed the review period from five to two years. According to this plan, the average growth rate of electricity demand between 2008 and 2030 was 2.1 per cent, from 390 TWh to 500 TWh. Total nuclear electricity generation and its share would rise from 148 TWh (35.5 per cent) in 2008 to 265 TWh (47.9 per cent) in 2022 and 334 TWh (59 per cent) in 2030 (Table 7.7). This would require a total investment of 2,621.56 billion Korean won.

National administration and main players

The organisation in charge of decision making on the use and development of nuclear energy in Korea is the Atomic Energy Commission (AEC), which reviews and decides the agenda submitted by MEST including the CNEPP and the Nuclear Energy R&D Plan. The chairman of the AEC is the prime minister of the country. The AEC consists of ministers from relevant governmental ministries, including the MKE, and also experts nominated by the president from universities, industries and research institutions.

MEST is responsible for developing and implementing R&D policies, allocating and managing nuclear R&D funds for the use and development of nuclear energy, overseeing export control of nuclear technologies, nuclear material control, nuclear safety regulation and technical cooperation for the use and development of nuclear energy. The NSC advises the Minister of MEST on the nuclear safety issues.

MKE is responsible for setting up the Basic Plan for Electricity Supply, nuclear industry development including the construction of nuclear power plants and the supply of nuclear fuel, and management of wastes from nuclear installations. It also regulates government-invested nuclear industries. The Ministry of Foreign Affairs and Trade is responsible for nuclear diplomatic affairs bi- and multilateral nuclear cooperation such as the conclusion of the nuclear cooperation agreement and relations with IAEA, Nuclear

Non-Proliferation Treaty (NPT), OECD/Nuclear Energy Agency (NEA) and so on. The National Energy Commission is responsible for long-term energy policy by establishing the Basic Energy Plan every five years including nuclear energy.

Currently, KHNP is responsible for project management, construction and operation of nuclear power plants; KEPCO is responsible for architectural engineering and design of the nuclear power system. KNFC is supplying nuclear fuel for nuclear power plants in Korea as well as designing and manufacturing nuclear fuel for PWRs and pressurised heavy water reactors (PHWRs). Doosan Heavy Industry is manufacturing various nuclear components such as a reactor vessel, and Korea Power Services is responsible for the maintenance of services at nuclear power plants. The Korea Radioactive Waste Management Co. Ltd was set up early in 2009 and it is responsible for the collection and management of radioactive wastes from nuclear installations such as nuclear power plants, radioisotopes industries, research organisations and so on. KEPCO is a state-owned corporation, playing a leading role in exporting Korean nuclear power plants to the overseas market through consortiums around the Korean nuclear industries.

Public attitudes towards nuclear energy

It was in the latter half of the 1980s that the public entered the debate on the nuclear energy projects in Korea. In the 1970s when people experienced the two oil crises and commercial operation of the first nuclear power plant, Kori unit No. 1, nuclear energy was recognised as an economic and reliable source of electricity, and the nuclear power project could be carried out without difficulty in selecting reactor sites and so on. The country was then governed by the military and an authoritarian regime and little opposition was spoken in public. 'The highest priority was given to the cost and quality assurance as well as the schedule management, [but] not as much attention was paid to such important issues as the public acceptance and radioactive waste management' (Choi et al. 2009: 5507).

The accident of unit II of the Three Mile Island nuclear power plant in the USA in 1979 and the Chernobyl nuclear power plant unit No. 4 in 1986 in the former Soviet Union highlighted the potential danger of nuclear power plants. These accidents made the public far more aware of and concerned over the safety of nuclear facilities including nuclear power plants. With the rising democratisation movement in the late 1980s, the media started reporting the tremendous damages of the nuclear bomb dropped in Japan in August 1945. The images of the damages caused by the nuclear bombing in Japan further strengthened the negative images of nuclear power plants.

The turning point of political changes in South Korea was the presidential election in 1987 which symbolised the people's movement for democratic revolution. A once highly centralised government was gradually decentralised and more power was transferred to local governments. Diverse citizens' groups with different causes and goals started to take centre stage. The public opposition to nuclear power programmes was joined by environmental groups that appeared during the course of democratisation. Together they demanded an input into the decision making in nuclear projects. In the 1990s, this proactive involvement of the public in nuclear energy development was facilitated by the widespread availability of electronic communications and information technology. As the public became more aware of nuclear safety issues, both nuclear regulatory agencies and nuclear industry were under pressure to communicate with the public. This reciprocal process became part of the larger process of democratisation in South Korea.

Meanwhile, public awareness of the nuclear safety issues made it more difficult for the industry to choose a site – 'not in my back yard' was the first difficulty the industry faced. Yet, the anti-nuclear movement in South Korea has never been as strong as that in many developed countries or even in Taiwan because of the widespread awareness 'that there was no way to secure sufficient electric utility without relying on nuclear energy' (Sung and Hong 1999: 314). This widespread awareness to a large extent shifted the attention of anti-nuclear movement in the country from stopping nuclear energy development to an emphasis on safety assurance. The government responded to this demand.

In 1990, the government decided to create an independent regulatory agency to ensure safety and to convince the public that it took the safety issue seriously. The Nuclear Safety Centre was created in 1981 as part of the Korea Atomic Energy Research Institute (KAERI). With increasing workload for the safety regulation and increasing public concerns for nuclear safety, the Korea Institute of Nuclear Safety (KINS) was established in the 1990s to be 'in charge of technical advices, supports, evaluations and activities in support of the ultimate decision making and approval by the Ministry of Education, Science and Technology' (Choi et al. 2009: 5497). In the mid-1990s, the government decided to institutionalise the public communication on nuclear development. In 1995, KINS conducted its first of a series of systematic public surveys on safety issues as a way to incorporate public communication into its decision-making process. More public surveys were conducted in 2000, 2002, 2004 and 2005 (Eun 2004).

The public opposition and scrutiny might have been considered by some in the industry as a 'nuisance' because it made it difficult for the industry to push forward the nuclear projects, especially in securing the sites for nuclear power plants. But to many others in the industry, the public concerns had important positive impacts on the industry because the regulators and the industry together improved their safety standards and the associated safety engineering capabilities. The improved safety record also allowed the country to expand its nuclear energy capacity while the nuclear programme was shelved in many other developed countries in the 1990s.

The public opposition was particularly apparent regarding the issue of nuclear waste storage. Over a period of 20 years (1986–2005), the government made nine attempts to select a site for the construction of a low- and intermediate-level radioactive waste disposal facility. 'After determining that much of the failure of the previous attempts was the result of the lack of a transparent and democratic process, in 2004 a more democratic process incorporating a referendum was implemented' (IEA 2006: 142). An elaborated process was initiated in December 2004 and in November 2005, several referenda were held at the proposed sites. Leading to the referenda, governments, the industry and environmental groups all launched hard campaigns. A decision was made in the following month on the construction of a low- and intermediate-level nuclear waste facility. Gyeongju City, located on the east coast, was decided as the site for the radioactive waste facility, with higher voting results in favour of that over Kunsan City located on the west coast of the Korean Peninsula.

This open and transparent process in which the public participated directly fostered more public support for nuclear energy expansion. Indeed, the proportion of people surveyed in favour of new nuclear power plants rose from a little over 20 per cent to nearly 70 per cent and a similar trend could be found among those in favour of nuclear energy expansion in general (Figure 7.1). The public support for nuclear energy rose even among those living in the current and potential sites (Table 7.8). Indeed, there is a

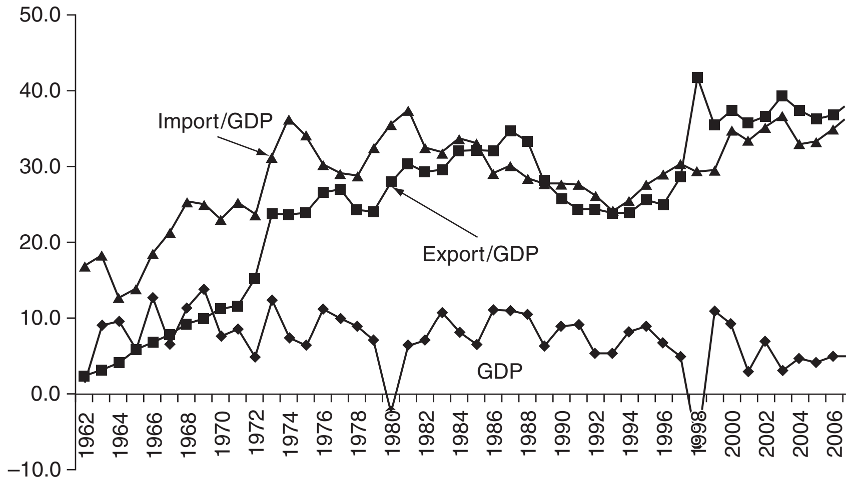

Figure 7.1 Trend of GDP, export and import growth rate in South Korea, 1962–2007
Source: SERI (2008).

Table 7.8 Factors affecting public opinion towards nuclear power plants in their neighbourhood

Classification	General Public (%)				
	1995	1997	2000	2006	2007
Environmental pollution	54.3	54.5	40.9	39.5	34.1
Diseases	17.6	22.0	28.8	36.9	37.7
Possibility of an explosion	19.2	12.6	18.7	6.9	8.0
Decrease in property value	1.5	2.8	3.3	5.6	8.6
Deterioration of occupational conditions	2.6	3.0	5.1	4.1	5.4
Obstacles in regional development	3.7	3.9	3.1	3.0	5.5

Source: Dongwon (2008a).

strong positive correlation between the public trust on safety and technology and their support for nuclear expansion.

Perspectives for nuclear power technology

Development of the Korean standard nuclear power plant came to a high level in the second half of the 1990s. YGN 3&4 were constructed with the aid of foreign supplies. After their successful operation in 1994 and 1995, the country started constructing the same model of nuclear power plants – the same reactor type and capacity – with a complete indigenous capacity. The first two KSNP plants, YGN 5&6, became operational in 2001 and 2002. Since then, the industry has focused its efforts on improving the technology, especially on its economic and safety design features. The Korean APR-1400 has been commercialised in Korea and it is expected that this model will be used up to 2020. APR+ as a successor of APR-1400 is at this stage under consideration in the country (Table 7.9).

The six units under construction in 2010 are all using the Korean reactors (Table 7.10).

KAERI has been developing a series of future innovative nuclear power reactors such as SMART (System-integrated Modular Advanced Reactor), Sodium Fast Reactor (SFR), Fuel Cycle-KALIMER (Korea Advanced Liquid Metal Reactor) and advanced fuel cycle technologies including pyroprocessing and NHDD-VHTR (Very High Temperature Reactor) for hydrogen production and so on.

In addition, Korea has joined GIF (Gen-IV International Forum) and participated in SFR, VHTR of six selected reactor types in GIF agreement. These reactors will be expected to be commercialised around the year 2030. Therefore, Korean future reactor development plans such as KALIMER and

Table 7.9 Nuclear power plants in operation in South Korea

Year of operation reactor name	Reactor supplier	Generator supplier	Architect engineer	Construction contractor
1978 Kori	Westinghouse	GE (UK)	Gilbert	Westinghouse
1983 Wolsong 1	AECL	NE (UK)	AECL	AECL
1983 Kori 2	Westinghouse	GE (UK)	Gilbert	Westinghouse
1985 Kori 3	Westinghouse	GE (UK)	Bechtel	Hyundai
1986 Kori 4	Westinghouse	GE (UK)	Bechtel	Hyundai
1986 YNG 1	Westinghouse	Westinghouse	Bechtel	Hyundai
1987 YNG 2	Westinghouse	Westinghouse	Bechtel	Hyundai
1988 Ulchin 1	Framatome	Alstom	Framatome	Dong Ah/Hanjung
1989 Ulchin 2	Framatome	Alstom	Framatome	Dong Ah/Hanjung
1995 YNG 3	Hanjung/C-E	Hanjung/GE	KOPEC/S&L	Hyundai
1996 YNG 4	Hanjung/C-E	Hanjung/GE	KOPEC/S&L	Hyundai
1997 Wolsong 2	AECL/Hanjung	Hanjung/GE	AECL/KOPEC	Hyundai
1998 Wolsong 3	AECL/Hanjung	Hanjung/GE	AECL/KOPEC	Daewoo
1998 Ulchin 3	Hanjung/C-E	Hanjung/GE	KOPEC/S&L	Dong Ah/Hanjung
1999 Wolsong 4	AECL/Hanjung	Hanjung/GE	AECL/KOPEC	Daewoo
1999 Ulchin 4	Hanjung/C-E	Hanjung/GE	KOPEC/S&L	Dong Ah/Hanjung
2002 YNG 5	Doosan	Doosan	KOPEC	Hyundai/Daelim
2002 YNG 5	Doosan	Doosan	KOPEC	Hyundai/Daelim
2004 Ulchin 5	Doosan	Doosan	KOPEC	Dong Ah/Doosan.Samsung
2005 Ulchin 6	Doosan	Doosan	KOPEC	Dong Ah/Doosan.Samsung

Note: Non-Korean Companies; non-Korean and Korean companies; Korean companies.

Source: IAEA (2001).

Table 7.10 Nuclear power development plan

Project		Reactor type	Capacity (MWe)	Model	Commercial operation	Remark
Shin-Kori	#1	PWR	1,000	OPR-1000	December 2010	Under construction
	#2	PWR	1,000	OPR-1000	December 2011	
	#3	PWR	1,400	APR-1400	September 2013	Under construction
	#4	PWR	1,400	APR-1400	September 2014	
	#5	PWR	1,400	APR-1400	December 2018	Planning
	#6	PWR	1,400	APR-1400	December 2019	
Shin-Wolsong	#1	PWR	1,400	OPR-1000	March 2012	Under construction
	#2	PWR	1,400	OPR-1000	January 2013	
Sgin-Ulchin	#1	PWR	1,400	APR-1400	December 2015	Under construction
	#2	PWR	1,400	APR-1400	December 2016	
	#3	PWR	1,400	APR-1400	June 2020	Planning
	#4	PWR	1,400	APR-1400	June 2021	

Note: OPR-1000: Optimised Power Reactor 1,000 MWe; APR-1400: Advanced Power Reactor 1,400 MWe; another eight nuclear plants are expected to be built between 2023 and 2030 depending on the future electricity demand.
Source: IEA (2006: 140).

VHTR will be carried out linking with related activities of the GIF R&D programme. Meanwhile, Korea has joined the IAEA multilateral project, International Project on Innovative Nuclear Reactors and International Thermonuclear Experimental Reactor (ITER) project for the development of nuclear fusion power technologies.

In December 2009, South Korea beat US General Electric in collaboration with Hitachi and the French Areva to win the first major nuclear export agreement – a four-year US$20 billion deal to export nuclear reactors to the United Arab Emirates (UAE). South Korea is also aiming to capture 20 per cent of the world market for nuclear reactors by 2030. The deal with the UAE included several major provisions:

- The KEPCO consortium will design, build, help operate and maintain, and provide initial fuel for four APR-1400 nuclear units at a total price tag of US$20 billion.
- Korean investors will have an equity interest in the UAE plants.

- The first unit is to begin commercial operation in 2017, with the other three to be completed by 2020.
- Extensive training, human resources development and education is to be provided to allow the UAE to eventually provide most of the nuclear power plant staffing and develop commercial infrastructure and support businesses.
- A potential follow-on contract for long-term operation and maintenance of the units, worth as much as another US$20 billion over 60 years, is under discussion (Holt 2010: 5).

Domestically, the government adopted a long-term national energy plan that emphasises low-carbon green growth. To prepare for a post-oil era, the government adopted four strategies: improving energy efficiency and lowering energy consumption; increasing shares of clean energy; assisting and boosting green energy industry; and securing an affordable supply of energy. Within this broad framework, the nuclear industry will expand as a core energy source and one of the main drivers for green growth. The nuclear industry will expand to increase the share of nuclear power generation from the current 36 per cent to 59 per cent by 2030. Some 40 nuclear power plants will be in operation by then.

Challenges are great too. It is still politically difficult to secure new plant sites. The public in general is more accepting of nuclear energy in Korea than in many other countries because of the country's lack of resources, but it remains to be seen how public acceptance can be secured for specific sites. Not-in-my-back-yard mentality is hard to overcome. Furthermore, Korea has always had an ambition to develop its full nuclear fuel cycle capability. According to Korean nuclear authorities, the country will run out of storage space for spent fuel by 2016. To address this issue, South Korea is in the process of developing a capability, named pyroprocessing, to reduce the volume and radioactivity of spent fuel discharged from its nuclear power plants and, potentially, to recycle it by using the transuranic elements in fast reactors. The USA currently provides the conversion and enrichment services of nuclear fuel and has no intention of letting South Korea develop its enrichment or reprocessing capacity, not only because of the concern of proliferation but more importantly because of the situation in the whole Korean Peninsular. The Korean nuclear energy industry developed under the ROK-US nuclear energy agreement, which was initially signed in 1972 and revised in 1974, will officially expire in March 2014. The main point of contention between the USA and South Korea in pursuing the renewed bilateral agreement is Korea's attempt to obtain advanced, long-term US consent to pyroprocessing or even reprocess US-origin spent fuel I fast reactors (Holt 2010; Kane 2010; Squassoni 2010).

South Korea has a thriving nuclear energy programme and advanced nuclear energy R&D. Motivated by growing overseas interest in nuclear energy, the Korean nuclear industry is aggressively seeking to expand to the new markets where currently there are no nuclear power plants. Doosan and other firms are also producing major reactor components for non-Korean reactors, such as the four Westinghouse AP1000 units being built in China. This has raised some serious concerns, especially in the USA, not only about American competitiveness in the industry but, more importantly, about the implication to the non-proliferation regime. The consortium led by KEPCO and formed after the deal with the UAE was signed did include Westinghouse as part of the project. Its desire to pursue 'nuclear sovereignty' (Kane 2010) – a drive for more independence in developing nuclear fuel cycle capabilities – is made laud and clear. Seeking nuclear expansion in South Korea and in overseas markets needs to be balanced with the concerns of non-proliferation.

Note

1. The Nuclear Safety Centre was created under the auspice of KAERI in 1982, and was upgraded as an affiliated institution in 1987. In 1990, NSC came out of KAERI and became an independent institution.

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8

The Past, Present and Future of Nuclear Power in Taiwan

Min Lee

Introduction

Nuclear power is a mature technology that has been used effectively and successfully for more than 50 years. Faced with increasing energy demands, concerns over climate change and dependence on overseas supplies of fossil fuels, many countries have turned to nuclear power. Nuclear power provides countries with energy security and generates power without emission of polluting products or greenhouse gases (GHG). Furthermore, the safety record of nuclear power is superior to that of other major energy sources. Undoubtedly, nuclear power will play a major role in future power generation.

Taiwan is a country that lacks domestic energy resources and nuclear power is a viable energy option. Its government's interest in nuclear power dates back to 1955. The world oil crisis in the early 1970s led to the first phase of Taiwan's nuclear energy development, in which four nuclear power plants (NPPs) with eight units were planned and consequently built. The building of the first three nuclear power stations went smoothly and since then nuclear energy has made a significant contribution to Taiwan's economic growth. In 2007, NPPs produced 38.96 TWh of electricity, accounting for 19.3 per cent of the total electricity generation and 7.97 per cent of primary energy supply in Taiwan. In 2008, the total installed nuclear capacity was 5144 MWe, or 13.5 per cent of Taiwan's installed electricity generation capacity. The cost of nuclear power is NT$0.63 per kilowatt hour (kWh), which also includes a contribution of NT$0.17/kWh to nuclear waste management and the decommissioning of plants, and it is significantly lower than that of electricity from fossil-fuelled power plants. The fourth NPP (units 7 and 8 of the Taiwan Power Company – TPC) was proposed and approved by the government in 1980. Its construction, however, did not start until August 1999. Ten years later, it was still not completed. Over the past 20 years, the building of the Lungmen Nuclear Power Station has been one of the major public controversies and a centre of debate by the two rival political parties in Taiwan, Kumintang (KMT) and the Democratic Progressive Party (DPP). After it took over as government in May 2000, the DPP adopted 'A Nuclear-Free Homeland' as a major government policy. The Legislative Yuan passed the Basic Environment Act on 11 December 2002. Article 23 of the Act states: 'The government shall establish plans to gradually achieve the goal of becoming a nuclear-free country.'

Two developments, the price hiking of fossil fuel starting in 2004 and the Kyoto Protocol which became effective in February 2005, convinced policy makers around the world to think seriously of the 'nuclear option'. In 2008, the newly elected KMT government acknowledged the importance of nuclear energy to the future economic development of the country. In the closing ceremony of the 2009 National Energy Conference of Taiwan, Prime Minister Dr Chao-Shiuan Liu stated that nuclear power was an important energy resource that would help the country achieve its goal of building a 'low-carbon homeland'.

This chapter discusses the experience gained and lessons learned in the development of nuclear power in Taiwan.

The necessity of nuclear power

The world's population stands at around 6.6 billion and it is estimated that this number will rise to 9 billion by 2050. A burgeoning world population will require vast amounts of energy to provide fresh water, energise factories, homes and transportation, and support infrastructure for nutrition, education and heath care. Statistics show that 1.4 billion people (or 20 per cent of the world's population) in developed countries consume 80 per cent of the world's resources, while 1.6 billion people have no access to electricity and 2 billion more have only limited access. Numbers of the same scale apply to clean water as world water tables fall under the demands of expanding human consumption. As a remedy, large-scale desalination of seawater is the only solution. The process is energy-intensive and this will compound global energy demand. It is generally believed that in less than ten years the energy consumption of developing nations will equal that of countries we now refer to as 'developed'.

A tremendous amount of energy is required to support the continuing development of human civilisation. In 2007, over 81 per cent of the world's primary energy supply (12,029 million tonnes of oil equivalent, Mtoe) was derived from fossil sources (IEA 2009b). It is estimated that global energy consumption will be doubled by 2050. Fossil reserves are limited and, more importantly, the burning of fossil fuel generates carbon dioxide. Climate change is real and the energy sector accounts for 84 per cent of global CO_2 emissions and 64 per cent of the world's greenhouse gas emissions. The consensus is that containing the Earth's atmosphere to no more than 450 parts per million (ppm) of carbon dioxide is necessary if we want to avoid catastrophic disasters. 'Meeting a 450 Scenario requires a fundamental change in our approach to producing and consuming energy, whether it is re-orienting our power generation mix away from fossil fuels and towards nuclear and renewables, maximizing the efficiency of our vehicles, appliances, homes and industries, or developing revolutionary technologies for the future, almost all potential sources of lower emission will need to be tapped' (IEA 2009b: 168).

Renewable energies, such as solar, wind, tidal and geothermal, all have roles to play in future energy supply. Energy conservation and improving energy efficiency will also help deal with climate change. But none of these tools can alter the fact that nuclear power offers the one available technology that can energise a thriving economy without destructive environmental impacts.

Status of nuclear power worldwide

The world's first civilian NPP, with a capacity of 6 MWe, reached its criticality at Obninsk in the former Soviet Union on 1 June 1954. The first pressurised water reactor with rated power of 60 MWe began its commercial operation at Shippingport Pennsylvania, USA, in 1957 (IAEA 1997). Today, 70 years after the discovery of nuclear fission and about 50 years after the operation of the first nuclear power reactor, there are 439 reactors in operation in 30 countries. The total installed capacity is 372 GWe. The total amount of electricity generated was 2,719 TWh in 2007, which is about 16 per cent of the world's total electricity generation and about 6 per cent of its primary energy consumption (IEA 2009a: 15–16). Civil nuclear power reactors have accumulated more than 12,600 reactor-years of operation experience. At the beginning of 2010, 57 reactors of 53,505 MWe are under construction in 15 countries (IAEA 2010a).

The installation of nuclear capacity rose relatively quickly in the early years, from less than 1,000 MWe in 1960 to 100,000 MWe in the late 1970s, and over 310 GWe by the end of the 1980s. It rose by only 18 per cent between 1989 and 2008 to 371 GWe (Table 8.1). Indeed, more than two-thirds of all nuclear plants ordered after January 1970 were eventually cancelled (IAEA 1997).

Nuclear power is a controversial issue and anti-nuclear advocates express their multiple concerns ranging from: the fear of possible nuclear accidents,

Table 8.1 Reactors in operation in the world

	1960	1970	1975	1980	1985	1990	1995	2000	2005	2008
No. of units	15	84	169	245	363	416	434	435	441	438
GWe	0.9	19.0	72.7	135.3	248.1	320.5	342.2	350.6	368.1	371.6

Source: IAEA (2009: 21).

radiation leaks, nuclear proliferation, and nuclear waste production, transport and final storage. The Three Mile Island incident of 1979 and the disaster of the Chernobyl nuclear power plant in 1986 played important roles in stopping the construction of new plants and in triggering the actions to start nuclear power phase-outs in several countries. Nevertheless, the 1973 oil crisis had a significant impact on energy policies in countries such as France, Korea and Japan, which relied heavily on imported primary energy for electric generation. The shares of nuclear power in the electricity generation in these countries were 77 per cent, 35.3 per cent and 27.5 per cent, respectively, in 2007.

After a long period of decline in the construction of NPPs, lately there has been a renewed interest in nuclear energy. Concerns about energy security and climate change are the two main reasons for the renewed interest. In 2002, the parliament in Finland decided to grant a licence for the construction of a fifth nuclear power station. This was the first such decision to build a new NPP in Western Europe for more than a decade. Many countries in Asia, such as Japan, China and India, are more active in expanding their nuclear energy.

The nuclear renaissance has revived debates about nuclear waste and safety issues. Some developing countries that plan to go nuclear have very poor industrial safety records and problems with political corruption. Most countries with nuclear power do not have a final solution for the disposal of nuclear spent fuel. Burying the spent fuel deep underground is the common solution, but no such long-term waste repositories yet exist. Some anti-nuclear advocates also raise concerns that the expansion of nuclear power will lead to a significantly increased risk of nuclear weapons proliferation and nuclear terrorism.

Status of nuclear power in Taiwan

Taiwan is a highly populated island country, with around 0.3 per cent of the world's population living on 0.6 per cent of the world's land. It consumes around 1 per cent of the world's total energy and 1.3 per cent of electricity. In 2007, electricity consumption per capita in Taiwan was 10,216 kWh, 3.7 times that of the world average and 21 per cent higher even than the OECD's average (IEA 2009a). The primary energy resources of power generation are 43.35 per cent coal, 21.39 per cent gas, 19.30 per cent nuclear, 5.86 per cent co-generation and 5.76 per cent oil. Almost all energy consumed in Taiwan is imported and hydro makes up the rest, but hydro heavily depends on weather conditions (Table 8.2).

The total amount of carbon emissions in Taiwan was 276 million tonnes in 2007 and its per capita emission 12 tonnes, three times the world's average (IEA 2009a). According to the International Energy Agency (IEA), Taiwan ranks 22nd for the total amount of CO_2 emissions and ranks 16th in CO_2

Table 8.2 Energy mix in Taiwan

Year	Oil (%)	Coal (%)	Nuclear (%)	Natural gas (%)	Hydro (%)
1990	55.4	23.3	13.9	3.8	3.47
1995	54.3	26.2	11	5.8	2.7
2000	50.9	31.1	9.1	6.8	2.1
2005	51.3	31.9	7.3	8.0	1.45

Source: Bureau of Energy, Ministry of Economic Affairs (2008).

emission per capita. In 2008, Taiwan ranked number one in the world in relation to its annual increase rate of CO_2 emission per capita.

In 2008 Taiwan had a total installed nuclear capacity of 5,144 MWe, accounting for 13.5 per cent of the total generating capacity. This was a significant decline from the peak in the mid-1980s when nearly 50 per cent of the country's total electricity was from NPPs (personal communication with Taipower staff). The Taiwan Power Company (Taipower) owns and operates six nuclear units and has another two under construction and both were expected to be commissioned in 2010 (Table 8.3):

Table 8.3 Nuclear power plants in Taiwan

Name	Type of reactor	Capacity (MWe)	Date of commissioning
Chin Shan 1	BWR	636	16 November 1977
Chin Shan 2	BWR	636	19 December 1978
Kuosheng 1	BWR	1019	21 May 1981
Kuosheng 2	BWR	985	29 June 1982
Maanshan 1	PWR	956	9 May 1984
Maanshan 2	PWR	921	25 February 1985
Lungmen 1	BWR	1350	Under construction
Lungmen 2	BWR	1350	Under construction

Note: BWR: boiling water reactor; PWR: pressurised water reactor.
Source: IAEA (2010b).

The capacity factor of these six operating units over the past five years is 88.5 per cent. The generation cost of nuclear power was 0.63 NT$/kWh in 2005, which included a contribution of 0.17 NT$/kWh to the nuclear waste management and decommission of the plant. About 16 per cent of the total cost was on nuclear fuel, of which 55 per cent was for purchasing uranium ore.

The fourth nuclear power project (Lungmen) started construction in August 1999 and ten years later, it is still not completed. Indeed, the project has been heavily debated for the past 20 years by the two rival political parties – KMT and DPP. This ill-fated project provides a valuable lesson for countries that are interested in developing nuclear power: that public acceptance and consensus among political parties are crucial for a successful deployment of nuclear power. The difficulties in the construction of the Lungmen nuclear power station of Taiwan are discussed later in this chapter.

Development of nuclear power in Taiwan

Taiwan launched its nuclear programme in 1955 after it signed a bilateral agreement with the USA on the peaceful use of atomic energy. The Atomic Energy Council, Taiwan (AEC) was established in the same year at a ministerial level, under the Executive Yuan, to coordinate the affairs related to nuclear energy and the government initiated a plan to construct a research reactor at National Tsing Hua University located at Hsin Chu, Taiwan. Nuclear development in Taiwan was government-led and government-financed as was the case in South Korea. All six nuclear reactors in operation now were constructed and completed under the authoritarian regime. The anti-nuclear movement emerged at the same time as the democratic movement spread across the island and since then nuclear power projects have been subject to increasing public scrutiny. Indeed, they have been one of the most contentious issues between the two rival political parties.

Taipower is a state-owned public utility, responsible for the production and distribution of electricity in Taiwan. Nearly two-thirds of Taiwan's power stations are owned by Taipower. In 1955, Taipower established an Atomic Power Research Committee, which was responsible for collecting information on nuclear power, sending experts to foreign countries to gain an understanding of the latest developments in nuclear power, exploring the possibility of building a nuclear industry in Taiwan, and drafting and executing training programmes. Deploying nuclear power is a complicated issue. The historical lessons in Taiwan's development of nuclear power are presented in the following sections.

Building the manpower required for the deployment of nuclear power

The Atomic Power Research Committee of Taipower initiated a long-term training programme in order to acquire the manpower required for the deployment of nuclear power long before the construction of the first NPP. Between 1968 and 1981, Taipower sent 583 experienced plant construction engineers and fossil power plant staff to foreign countries to learn how to build and operate NPPs. The host institutes of the training programme included universities, vendors of nuclear steam supply system (NSSS) and nuclear power utilities. Later, the training programme was transplanted back to Taiwan. The Department of Nuclear Engineering of National Tsing Hua University played a major role in setting up the domestic training programme of nuclear engineers.

National Tsing Hua University was re-established in Taiwan in 1955 and the major focus of the university at the time was nuclear science and engineering. The university created the first research nuclear reactor in the country. The Institute of Nuclear Science (master programme) was founded in 1956, which was the first academic unit at the university. The construction work for the Tsing Hua Open-Pool Reactor (THOR) began in December 1959 and the first self-sustained nuclear chain reaction was reached on 19 April 1961. This was the country's first step towards the nuclear era. The university established undergraduate and master's programmes in the Department of Nuclear Engineering in 1964 and 1970, respectively, and doctoral programmes in 1980. In 1992, the Institute of Nuclear Science evolved into the Department of Nuclear Science to include undergraduate education. Because of the stagnation of nuclear power around the world, and in Taiwan itself, the Department of Nuclear Engineering was changed to the Department of Engineering and System Science (ESS) in 1997 and the name of the Department of Nuclear Science was changed to the Department of Biomedical Engineering and Environmental Sciences in 2006. In response to the nuclear renaissance and the renewed interest in the country for nuclear power, the university re-established the Institute of Nuclear Engineering and Science in 2007.

The graduates of these programmes have played a major role in the nuclear development in Taiwan. Most of the managerial positions in the nuclear branch of Taipower and in the regulatory body (the AEC) of government are held by the alumni of the department. Human capital is the key to a successful nuclear energy programme in all countries wishing to develop and expand nuclear energy programmes.

Building nuclear power plants

In the early 1960s, Taipower incorporated nuclear power in its long-term planning for power grid construction. The site selection process of an NPP was initiated in 1965. With the assistance of experts from the International Atomic Energy Agency (IAEA) and an engineering consulting company from the USA, several potential sites were identified. In the first phase of the nuclear power development plan, it was decided that four plants and eight nuclear units were to be built. Each site would be able to host more than two units. In total, around 20 units were planned for the four selected sites. The construction of the first nuclear power station in Taiwan, Chinshan, started in November 1970. The Atomic Power Research Committee of Taipower evolved into the Division of Atomic Power in 1972. Construction on the second, Kuosheng, and the third, Maanshan, nuclear power stations was started in August 1975 and April 1978, respectively. A fourth NPP was proposed in May 1980 and was approved soon after by the government. The project, however, was postponed following the economic slow-down after the second oil crisis in 1982 and the consequent decline in electricity demand.

Table 8.4 Schedule and budget of Taipower's nuclear power plants

Unit 1		Chinshan	Kuosheng	Maanshan
Date of commercial operation	Scheduled	Mar 1975	Apr 1980	Feb 1984
	Actual	Dec 1978	Dec 1981	Jul 1984
Budget Billion NT$	Original	12.80	21.96	35.77
	Actual	29.62	63.04	97.44

Source: Personal communication with Taipower.

Table 8.5 Median construction time span in the world, 1976–2008

	1976–80	1981–85	1986–90	1991–95	1996–2000	2001–05	2006–08
World	74	99	95	103	146	64	80
Taiwan	64	72					

Source: IAEA (2009: 23).

Like many nuclear power projects around the world at the time, the nuclear power projects in Taiwan also suffered significant schedule delays and an escalation of the costs (Table 8.4).

Construction time delay in Taiwan was nearly as bad as the world average (Table 8.5), but the cost overrun raised serious concerns. Furthermore, the construction schedule delays for the fourth plan (Lungmen) until 2009 were already double the construction time span in other parts of the world.

There are several major players in the construction of NPPs: owners, vendors of NSSS, vendors of turbines and generators, suppliers of key components, an engineering consulting company that is responsible for the detailed design of the plant, constructors, the company in charge of project control and management (PCM) and the regulatory agency of the government. Any developing country that is considering nuclear power must be aware that the risk – the construction of a nuclear power station will not be completed on schedule and on budget – is very high. The experience and capability of the company in charge of PCM play a vital role in the success of a project.

Operation of nuclear power plants

Operating an NPP requires a great deal of experience and the power industry has had to come to terms with these difficulties. One lesson learned from the Three Mile Island accident in 1979 is that better management of nuclear plants is vitally important for their safe operation. Safety measures must ensure that a plant shuts down automatically if there is a malfunction of the sub-system or if there is any violation of normal procedures.

The capacity factor of a nuclear plant is the most important factor in determining the generation cost of a plant. Continuing operation of a nuclear

Table 8.6 World average factors of nuclear power plants, 1990–2008

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008
%	72.9	77.7	83.6	85	84.6	81.7	84	84	83.9	82.6	80.8

Source: IAEA (2009).

plant is the key to its safety and therefore efficiency. This explains the steady increase in capacity factor in all NPPs around the world after the Chernobyl disaster in 1986. From 1990 to 2008, the world's nuclear generation capacity expanded by 51 GWe (23 per cent, due to both the net addition of new plants and the up rating of some established ones) and electricity production rose by 708 TWh, an increase of 37.5 per cent (IAEA 2009: 19). The relative contributions to this increase were new construction (36 per cent), power up rating (7 per cent) and increase in capacity factor (57 per cent). Indeed, the world average utilisation rate of NPPs increased from merely 73 per cent in 1990 to 81 per cent by 2008 (Table 8.6). Almost one-third of the world's reactors have capacity factors of more than 90 per cent, and more than two-thirds are higher than 75 per cent, compared with about 25 per cent of NPPs operating above that level in 1990.

In Taiwan, the capacity factor of the six nuclear power reactors improved from about 70 per cent in the mid-1980s to the current 90 per cent. Other indicators can be used to measure the performance of an NPP including the number of scrams (emergency shutdowns of a nuclear reactor), the collective dose (a measure of the total amount of effective dose multiplied by the size of the exposed population), the amount of low-level waste generated, and the fuel reliability. The number of scrams dropped from the peak of 30 in 1984 to only one in 2004 and 2–3 in the last two years.

The significant improvement in Taipower's operation of nuclear plants over the years can be attributed to pressure from anti-nuclear advocates and organisations. Taipower has implemented several initiatives to promote a safety culture among workers and engineers in the nuclear sector. The philosophy and strategy for operating an NPP and a fossil power plant are very different. The campaign for better industrial safety, radiation safety and nuclear safety is a never-ending process. To control nuclear power requires new managerial concepts and a new working culture.

Management of low-level radioactive waste

The operation and decommissioning of NPPs generate low-level radioactive wastes. Various applications of radiation – such as industrial, medical and research – also generate nuclear wastes. Low-level radioactive wastes need to be isolated for several hundred years. Technically, long-term storage of low-level radioactive waste is available and feasible. There are 74 low-level waste repositories in operation in 34 countries. Nevertheless, politically the site selection process is a controversial and time-consuming issue and public acceptance is the dominant factor in making a final decision.

Up to 2008, Taiwan had accumulated 188,434 drums (55 gallons) of low-level waste, with 90 per cent of the waste generated from NPPs. The waste drums are either stored in an interim storage facility located on Orchid Island or in a warehouse on the site of the NPPs. Orchid Island, with a size of 45.7 square kilometres, is located in the Pacific Ocean 91 degrees south-east of Taitung. It has 4,183 residents (2009 February). Most of the residents (77 per cent) are Aborigines. The decision to construct an interim storage facility of low-level waste at Orchid Island was made in the late 1970s and the facility began operation in 1982. The government chose Orchid Island as the location on which to build the interim storage of low-level waste because there is a deep oceanic trench in the region and the geology of Orchid Island is suitable for building the final disposal repository. At the time, dumping solidified low-level nuclear waste into the ocean was not formally forbidden by international law.

In the 1990s, local residents and anti-nuclear activists organised protests against using the island as a deposit site for nuclear wastes. The shipment of low-level waste to the site was made in 1996. Closing the facility and shipping out all the waste were two of the issues debated during the construction of the fourth NPP. Taipower once promised to ship the low-level waste out from Orchid Island by 2002, but it broke the promise because it failed to secure a potential repository site at a small island near the coast of mainland China.

It is estimated that to store the total amount of low-level nuclear wastes from NPPs of Taipower would require an area of 1 square kilometre for the repository. For a highly populated island, this becomes a difficult challenge. Taipower, under the supervision of AEC Taiwan, initiated a process to identify potential sites for the final repository, and would like to have a repository built by 2016.

Over the past 20 or so years, Taipower and AEC have spent a great deal of effort finding a site for the repository of low-level waste. Various criteria were set by a special committee for the site selection processes. From the initial three potential sites, the government chose two sites for submission to a referendum of local residents in June 2010. Without support from other branches of the government and politicians of the ruling party, the site selection of a low-level waste repository is a process that never ends. Site selection for nuclear waste deposit is more political than technical or economic in nature.

Management of spent fuel

One challenge all countries wishing to develop nuclear energy programmes must face is what to do with the spent fuel discharged from nuclear power reactors, which needs to be managed with great care. The spent fuel contains a large amount of uranium and plutonium that are valuable energy resources. Reprocessing spent fuel was abandoned in the 1970s in the USA because of the economic costs and concerns about nuclear proliferation. The American government opted for the open ('once-through') cycle. The spent fuel was not processed and currently is stored on site. It was proposed to build a permanent geologic repository facility in the Yucca Mountain in Nevada, and the facility was scheduled to become operational in 2020. However, the project has encountered significant delays. Currently, the amount of spent fuel already discharged in the USA is approaching the legal capacity of Yucca Mountain and the Obama Administration announced officially that the Yucca Mountain site would not be put into operation.

France, on the other hand, chose the 'closed fuel cycle' at the beginning of its nuclear programme. The closed fuel cycle strategy allows the extraction of remaining fissile material (uranium and plutonium) from the spent fuel and the recovered fissile materials are then recycled. At the same time, the volume and radio-toxicity of the ultimate waste are significantly reduced. The nuclear fuel cycle policies adopted by Japan, Switzerland, Russia, India and China chose to reprocess their spent fuels, while many other countries have adopted a 'wait and see' strategy and store the spent fuel for an indefinite period.

Of the 10,000 tonnes of heavy metal discharged annually from nuclear power reactors around the world, only approximately 30 per cent has currently been reprocessed. The total amount of spent fuel cumulatively generated worldwide by the beginning of 2004 was close to 340,000 tonnes of heavy metal, of which only 90,000 tonnes has been reprocessed. The annual discharge amount is estimated to increase to 11,500 tonnes of heavy metal by 2010.

Projections are that the world energy demand will more than double by 2050, and the expansion of nuclear energy is key to meeting this demand while reducing pollution and the emission of GHG. Early in 2006, the USA decided to revise its back-end policy of nuclear power and to consider recycling as part of its nuclear strategy through a US Department of Energy (DOE) Global Nuclear Energy Partnership (GNEP) initiative. GNEP aims for a system of industrial services and supplies guaranteed to support the fully controlled expansion of nuclear power across the world, which complies with non-proliferation requirements. Through this initiative, the US Administration confirms that nuclear power must play a major role in meeting the growing demand for energy around the world. It also constitutes recognition of treatment and recycling, which aims to recover the energy content of spent fuels and minimise the amount of final high-level waste as a solution for the sustainable development of nuclear power. On 21 May 2007, five countries with major nuclear power programmes (China, France, Japan, Russia and the USA) agreed on a joint statement of principles on the GNEP. This joint statement affirms a common vision of 'expansion of nuclear power, realising its contribution to sustainable development and assistance in meeting the worldwide growing energy demand'. In June 2009, the US DOE announced that it is no longer pursuing domestic commercial reprocessing, and had largely halted the domestic GNEP programme of the USA. Nevertheless, they indicated that research would continue on proliferation-resistant fuel cycles and waste management.

Taiwan adopted nuclear power technology from the USA. When nuclear power was first introduced, the policy makers envisioned that the USA would take back the spent fuel for reprocessing. Because there is great uncertainty in pursuing a closed fuel cycle, the Taiwan government decided to dispose of the spent fuel directly in a repository. Taipower started a long-term, multi-phase research and development programme for the final disposal of nuclear spent fuel in May 1986. In accordance with the Nuclear Materials and Radioactive Waste Management Act 2002, Taipower submitted a Programme Plan for Final Disposal of Spent Nuclear Fuel to the AEC in 2004. The AEC approved the plan in July 2006. According to this plan, the spent fuel disposal programme would be carried out in five phases:

- Potential host rock characterisation and evaluation (2005–17).
- Candidate site investigation and confirmation (2018–28).
- Detailed site investigation and testing (2029–38).
- Repository design and licence application (2039–44).
- Repository construction (2045–55).

Currently, all the spent fuel assemblies are stored in the spent fuel pools of an NPP. At the end of September 2007, the total inventory of spent fuel amounted to 13,666 fuel assemblies, containing about 2787 tonnes of uranium generated and stored on site. The spent fuel pool capacities of the two earlier boiling water reactor (BWR) plants are not large enough to cover the 40-year operation of the plants. For Chinshan NPP, it was expected that the pools would lose full core offload capability by March 2010. The interim storage of spent fuel in dry storage casks is planned for these plants. The construction of the dry storage cask facility faces strong opposition from local municipal government, local residents and anti-nuclear advocates. The licence for the construction is in the hands of the governor of the local municipal government (Taipei County), which demanded Taipower and AEC specify a firm target date to ship out spent fuel before the construction permit was granted. The continued operation of the existing facilities is jeopardised by the lack of a clear plan for nuclear spent fuel management that can be trusted by the public.

The back-end fund of nuclear power

The nuclear back-end fund covers the cost of the final disposal of low-level waste: packaging; transport; interim storage and final disposal or reprocessing of spent fuel; decommissioning of Taipower's nuclear facilities; and disposal of decommissioning waste. The nuclear back-end fund for Taiwan was established in 1986 and is being managed by an ad hoc committee under the Ministry of Economic Affairs, which consists of 13 members from government organisations and academic institutes. The total cost of six operating units was estimated to be NT$275 billion (about US$8.3 billion) at the currency value of 2001. Of the estimated cost, 60 per cent is associated with the interim storage and final disposal or reprocessing of spent fuel, and this estimated cost will be updated periodically. The rate of the back-end fund was NT$ 0.17/kWh in 2009, and can be adjusted annually so that it would adequately accommodate cost inflation. As of the end of June 2009, the total amount of the fund topped NT$196.2 billion (about US$5.9 billion).

Regulatory agency

The Atomic Energy Council (AEC) was founded in 1955 at the ministerial level under the Executive Yuan and is the sole authority within the central government directly overseeing atomic energy-related affairs. The council members consist of ministers of different branches of central government and scholars from universities. The primary mission of AEC is to protect public health and safety, and the environment from the effects of radiation from nuclear materials and facilities. The organisations of the AEC consist of the Department of Planning, the Department of Nuclear Regulation, the Department of Radiation Protection, the Department of Nuclear Technology, the Radiation Monitoring Centre, the Fuel Cycle and Materials Administration and the Institute of Nuclear Energy Research (INER). The missions of these organisations are developing and enforcing regulations, conducting R&D of nuclear technology, protecting against natural and man-made ionising radiation, overseeing the handling and final disposal of nuclear waste and coordinating international cooperation on nuclear energy. The National Nuclear Emergency Response Centre, led by the AEC minister, oversees off-site nuclear emergency preparedness and management, while the facility operator (Taipower) takes charge of the on-site mission. The Fuel Cycle and Materials Administration of AEC is the government organisation in charge of the management of nuclear waste.

INER is a national research institute and is the technical arm of the regulatory agency. INER has more than 1,000 employees and also plays a role in the technical support for the operation of the Taipower NPP.

Taiwan adopted its nuclear power technology from the USA, and its regulatory system is consequently directly transplanted from the USA. In the early days of the development of nuclear power in Taiwan, AEC did not have sufficient manpower and capabilities to conduct the review of the 'Preliminary Safety Analysis Report', to issue the construction permit and review the 'Final Safety Analysis Report' and to issue the operation licence. The review work was contracted out to US engineering consulting companies. In the early 1980s, after four to five years of commercial operation of the first nuclear power unit, the Department of Nuclear Regulation of AEC gradually built up the capabilities and manpower required for the oversight of the safe operation of NPPs. Consequently, the nuclear industry is probably the most regulated industry worldwide. The confidence and trust of the public in the governmental nuclear regulatory agency is a crucial factor in the public acceptance of nuclear power. In the debate over nuclear power, the capabilities of the agency and the transparency of the regulatory processes are always the concerns of anti-nuclear advocates.

Construction of the Lungmen nuclear power station

Background information

The fourth NPP, Lungmen nuclear power station of Taiwan, is located on the northeastern coast of Taiwan. It is about 20 kilometres southeast of Keelung City and 40 kilometres east of Taipei City. The entire site property is about 480 hectares. The building of the fourth nuclear power project (units seven and eight of Taipower) was proposed and approved by the government in 1980. After the Chernobyl nuclear disaster of 1986, Legislator Yuan (congress) voted to freeze the budget for the construction. In the same year, the opposition DPP was founded. DPP made nuclear energy a political issue and stated that the party would not support the construction of any new NPPs in Taiwan. Since then, the fourth NPP has become the major focus of the political struggle between the ruling party KMT and the opposition party DPP.

In 1992, the Legislative Yuan passed a resolution, reinstating the budget for the construction of the plant. In May 1994, Gongliao residents (the village where the plant is located) had their first referendum, with 96.45 per cent voting against building the plant. Anti-nuclear advocates organised a large-scale rally to protest about the government decision. In May 1996, a proposal to halt the construction of the plant was successfully passed in the Legislative Yuan, with a majority vote of 76. In June of the same year, the Executive Yuan sent a request to the Legislative Yuan asking for reconsideration. In October 1996, the Legislative Yuan passed the motion of the reconsideration, by 83 votes. The Preliminary Safety Analysis Report of Lungmen nuclear power station was submitted to the AEC on 16 October 1997. The construction permit of Lungmen nuclear power station was issued on 17 March 1999, and the first concrete was poured on 31 March 1999.

The Lungmen nuclear power project, which employs an advanced boiling water reactor (ABWR), is a two-unit facility. The rated electric power is 1,350 MWe per unit. The rated thermal power level is 3,926 MWt and the design power level is 4,005 MWt. General Electric Nuclear Energy Division and its associates are responsible for the design of the NSSS. Mitsubishi Heavy

Industries (MHI) is responsible for providing the turbine generator and related auxiliary systems, including the related control systems and instrumentation. Engineering support is provided by Stone & Webster (S&W). Taipower maintains control over and oversight of the design engineering process. The completion of the project was delayed several times and still not completed by early 2010.

Re-evaluation of the fourth nuclear power plant project

The DPP won the presidential election on 18 March 2000, and Shui-Bian Chen became President of the Republic of China. The 'termination of the construction of the 4th NPP' was one of President Chen's promises during the election campaign. On 26 May 2000, the new Minister of Economic Affairs, Hsin-Yi Lin, announced that he would organise a committee to reassess the feasibility of the fourth NPP project. The members of the Re-evaluation Committee of the fourth NPP project consisted of 18 members, of which six were from the government agency, two were from the Legislative Yuan and the rest were invited experts from universities, research institutes and industry.

The Re-evaluation Committee of the fourth NPP project held 13 meetings between 16 June and 15 September 2000. Each meeting lasted for six to seven hours and the topics covered included the worldwide trend of nuclear energy development, safety, risk and emergency planning of NPPs, nuclear waste; decommissioning, environment and ecological impacts of nuclear power, alternatives to the fourth NPP, the cost of its power generation, the social impacts, government policies on economics, energy and the environment, and the future of the fourth NPP project. At the first meeting of the Re-evaluation Committee, all the members agreed that the committee would not vote to determine the future of the fourth NPP project. The primary responsibility of the committee was to provide the necessary information for the government to make the final decision. The meeting was broadcast live on the Internet and was video-taped for broadcast on public television at a later date.

After the discussion of the first topic, it became clear that it would be difficult to reach consensus among the committee members who already had strong opinions about nuclear power. It was then decided that members of the committee would be split into two groups to write their separate reports and recommendations. One group was in favour of the continuing construction of the fourth NPP and the other group was in favour of its termination. After a long discussion in the final meeting, the committee members reached the following agreement:

1. The construction of the NPP is a controversial issue. It is not a simple issue of power demand and supply. It is a complicated problem related to the government policies on energy supply, economic development and

environmental protection. It is also a social and a political issue. The issue will have an impact on national security too.
2. The continuing construction or the termination of the fourth NPP project should not jeopardise the sufficient and the stable supply of electric power, which is a necessary condition for the economic development and a comfortable daily life for citizens.
3. In solving the problem of the lack of domestic energy resources, the government should adopt policies for diversified energy development, which include promotion of energy saving, promotion of increasing energy efficiency (power generation and consumption), promotion of the use of renewable energy resource, adjustment of industrial structure and deregulation of the electric power industry. These policies are consistent with the international requirements on sustainable development and environmental protection.
4. The final disposal of nuclear waste is an existing problem and should be treated in a responsible manner.

This ambiguous agreement of the Re-evaluation Committee of the fourth NPP project had no impact on the decision of the government in the cancellation of the fourth NPP project. The meetings of the Re-evaluation Committee gave the anti-nuclear and pro-nuclear groups a chance to argue about (but not really discuss) the related issues of nuclear power.

Suspension of the construction of the fourth NPP

On 29 September 2000, Minister Lin of the Ministry of Economic Affairs announced that he had recommended to Premier Tang that the construction of the fourth NPP should be terminated. The suggestion put great pressure on Premier Tang who favoured the completion of the project and Premier Tang resigned on 3 October 2000. The resignation of Premier Tang was a strong indication that the government had decided to terminate the construction of the fourth NPP.

On 27 October 2000, the leader of KMT, Tzn Lien, and President Chen met to discuss how to relax the tension that existed between the ruling DPP and opposition parties. Tzn Lien was the former Vice-President and a Presidential candidate representing KMT in the March 2000 election. The meeting was considered by the public and the media to be a major breakthrough in relations between the DPP and KMT, and certainly it was hoped that the meeting would end the long standoff between the parties. In the meeting, Tzn Lien suggested that the government should complete the construction of the fourth NPP and since the newly constructed NPP is safer and better than the old plants, the old NPPs in Taiwan could be replaced by the fourth NPP.

Almost immediately after the meeting, Chun-Hsiung Chang, the new Premier, announced in a press conference that the Executive Yuan had decided to terminate the project. In the announcement, Premier Chang said that safety concerns in the NPP were one of the major reasons the project was terminated. He believed that nuclear waste was a problem without a solution and halting the development of nuclear power was a worldwide trend. He also pointed out that the termination of the fourth NPP would not cause power shortages during the next seven years and that the power generated by the fourth NPP could be replaced with a gas-fired plant built by independent power producers. The day after the announcement, Taipower stopped all construction activities on the site and notified General Electric (GE) that the project was 'suspended'.

The announcement of Premier Chang surprised the public and greatly increased the tension between the ruling DPP and the opposition parties. The media used the phrase 'the explosion of a political atomic bomb' to express the impact of the announcement on the political stability of the country.

Resumption of the construction of the fourth NPP

Taipower is a government-owned company. The budget for the fourth NPP project had been approved by the Legislative Yuan. The opposition parties argued that, from a constitutional point of view, the Executive Yuan did not have the right to cancel the project. In order to justify that the Executive Yuan had this right, it asked the Grand Justice of Judicial Yuan to interpret the Constitution in the Constitution Court on 10 November 2000.

The Grand Justice announced their decision on 15 January 2001. In the announcement, the Grand Justice did not say that the Executive Yuan had no right to terminate a project approved by the Legislative Yuan; nevertheless, the new government did have the right to change major national policy. However, the Executive Yuan had to 'report' to the Legislative Yuan about its decision and ask for approval. The Grand Justice also made three suggestions as to how to solve the constitutional crisis surrounding the construction of the fourth NPP. Following the suggestions of the Grand Justice, on 30 January 2001, Premier Chun-Hsiung Chang presented a formal report to the Legislative Yuan.

In the report, Premier Chang mentioned that the ultimate goal of the government was to close down all NPPs in Taiwan and, therefore, the construction of the new NPP should be terminated. The slogan used was 'a nuclear-free homeland'. The legislators in the opposition parties insisted that the construction of the fourth NPP was approved by a constitutional process. Therefore, they concluded, the continued construction of the plants should be unconditional. The DPP was the minority party in the Legislative Yuan.

On the second day after the report was handed down, the Legislative Yuan voted on the issue and asked the Executive Yuan to resume the construction of the plant. The decision of the Legislative Yuan ignited another round of arguments among the politicians of the DPP and opposition parties that created a deadlock between the Executive Yuan and the Legislative Yuan on the issue. Finally, President Chen compromised. After several rounds of negotiation a memorandum was signed by the Executive Yuan and the Legislative Yuan. According to the memorandum, the Executive Yuan would resume construction of the fourth NPP and would send an 'Energy Bill' related to the nuclear energy issues to the Legislative Yuan for approval. The memorandum also stated that 'A nuclear-free homeland' was the consensus among all the political parties. After the memorandum was signed, Premier Chang announced the resumption of the construction of the fourth NPP on 14 February 2001 (Wang 2006).

Upon receiving the agreement Taipower notified all the contractors and demanded a resumption of the construction work immediately. In the announcement, Premier Chang also stated that the first nuclear unit of Taipower (Chinshan 1) would be closed down at the end of 2011, by which time the unit would have been in operation for 32 years.

Knowing that his decision would be challenged by the supporters of the DPP, President Chen promised that a public vote on the fourth NPP would be held in conjunction with the election due at the end of year. If the public voted in favour of termination of the project the fourth NPP would be officially cancelled. To prepare for the public vote on the issue, President Chen asked the Executive Yuan to propose a law to allow a public vote on the major national policies. The opposition parties argued that the new law should not apply to the construction of the fourth NPP and the Legislative Yuan would not pass the law if the Executive Yuan insisted upon it.

The Executive Yuan threatened that the vote would be set at the election held at the end of the year, even without the new law in place. The anti-nuclear advocates organised a demonstration on 24 February to protest against the decision and asked for the right to vote on the issue. In response to the request, the Executive Yuan organised a special committee to assess the impact if a public vote on the issue was carried out during the election at the end of the year. After a lengthy debate, the special committee suggested on 31 July that the issue of the construction of the fourth NPP should not be put to the vote at the election. The committee was worried that a negative public vote on the issue might inflict another major blow to the fragile economy of the country. However, this decision implied that President Chen had broken his promise to the supporters of the DPP.

Impact of suspension on the project

Construction work on the fourth NPP was suspended for 111 days between 27 October 2000 and 14 February 2001. There were two major consequences of the suspension on the project – a delayed construction schedule and the cost involved.

This impacted on the schedule as the original target date of the commercial operation of the first unit of Lungmen project was 16 July 2004. However, the date of the commercial operation was pushed back to 16 December 2004 due to the delay in obtaining the construction permit from AEC. The construction was eventually commenced on 14 February 2001. Taipower revised its completion date to 15 July 2006. According to the revised schedule, the 111 days of work suspension caused a delay of 576 days in the commercial operation. For some contractors, the workforce designated to the project was dissolved during the work suspension. The staff of the General Electric Nuclear Energy Lungmen task force was reduced from 300 to 100 upon receiving notice of the project suspension. It took time to organise a new team and to put the project back on track. The design and procurement processes of the project were also delayed significantly because Taipower was forbidden to decide on the contractor and supplier of the major auxiliary components during the period of the re-evaluation. It was believed that the possibility of holding a public vote on the issue at the end of 2001 also played a role in the severe delay in the schedule. The contractors remained sceptical that the government had given up the idea of terminating the fourth NPP. Consequently, the confidence and morale of the staff of Taipower and of the contractors was extremely low for a long time.

Taipower is a government-owned utility and the high-ranking managers of the company are appointed by the government. Consequently, it was politically incorrect for them to pay a great deal of attention to a project that was not favoured by the government. For the period between 2001 and 2007, Taipower had five Board chairmen and none of them visited the construction site during this period.

Since the resumption of construction, the date of commercial operation of the plant has been rescheduled twice. In December 2005, Taipower submitted an application to the Ministry of Economic Affairs to postpone the fuel loading date to October 2008 and the commercial operation date to 15 July 2009. The date of the commercial operation was revised again in February 2009. The latest target date for the fuel loading and commercial operation of unit 1 is 15 December 2010 and 2011, respectively.

There was a budgetary impact as well. The total budget approved by the Executive Yuan for the fourth NPP at the beginning of the project was NT$169.73 billion. The costs were allocated for two 1,000 MWe units and estimated based on a currency exchange rate of 1:27 and an annual inflation rate of 4.5 per cent. The cost included the construction, the first fuel loading and interest during the construction. The budget was revised to NT$208.21 billion during the re-evaluation. The escalation of the cost was due to the change in power level from 1,000 MWe to 1,350 MWe and the depreciation of the NT dollar. It was estimated by the Ministry of Economic Affairs that the loss through termination of the fourth NPP was between NT$75.1 and NT$90.3 billion.

At the beginning of 2001, the Legislative Yuan passed a budget of NT$3.49 billion to cover the costs during the period of suspension from 27 October 2000 to 15 February 2001. The cost due to the interest payment during this period was NT$0.555 billion. The cost of construction management during the period was NT$0.255 billion and the compensation to local contractors and foreign contractors was NT$0.565 billion and NT$2.114 billion, respectively.

Since the suspension caused a significant delay in the construction of the fourth NPP project, the contractors demanded compensation for the extra costs. The actual losses of the contractors are difficult to estimate and verify. Taipower negotiated with each individual contractor about the compensation for the losses due to the schedule delay. The actual amount of compensation each contractor received was confidential so the public would not know the total cost of the 111 days suspension of the construction of the fourth NPP.

The cost of the project also escalated significantly not only because of the delay in construction, but also because of inflation and the price hike of raw material around 2003. The approved budget before the suspension was NT$208.2 billion, but this figure was revised in December 2005 to NT$233.5 billion. It was revised again in February 2009 to NT$273.5 billion.

Another cost of the delay in the commercial operation of the fourth NPP was the fuel cost of the replacement power. The actual cost of fuel, of course, depended on the fuel prices at the time. According to figures in the report prepared by Taipower for the Re-evaluation Committee, the average fuel costs of coal and natural gas will be NT$1.368/kWh and NT$3.395/kWh, respectively, over the next 25 years. Assuming the capacity factor of the plant will be around 80 per cent, a rough estimation of the cost of the replacement power for six years will be between NT$77.6 and NT$192.7 billion.

Public acceptance of the project

A number of polls have been conducted to gauge public opinion of the suspension and resumption of the construction of the fourth NPP. In the poll made by MunSangPoh via the Internet on 12 April 2000, 38.8 per cent of the population said that construction of the fourth NPP should be continued if there were no better alternatives. If the site of the fourth NPP could be used to build a gas-fired power plant, 55.55 per cent of the population agreed that the construction of the fourth NPP should be stopped. Conversely, 22.22 per cent of the population disagreed. If the phase-out of nuclear power implied a higher rate of electric power, 40.7 per cent of the population would accept, but 51.85 per cent of the population would not accept.

In the poll conducted by TVBS (a cable TV station) on 4 May 2000, 43 per cent of the population did not feel confident that Taipower had the ability to handle an NPP accident. Also, 51 per cent of the population did not want to live near an NPP.

The poll results published in *China Times* on 8 May 2000 showed that about 30 per cent of the population living close to the site (near Keelung City and Taipei County) wanted to terminate the construction of the fourth NPP. About 10–20 per cent of the population living in other areas wanted to terminate the construction.

A poll conducted by the DPP on 18 September 2000 showed that more than half the population favoured the termination of construction of the fourth NPP, if they were offered alternatives to avoid power shortages.

In a poll conducted by KMT in 2000 immediately after Minister Lin suggested terminating the construction of the fourth NPP, 52 per cent of the population living in Taipei County favoured construction of the fourth NPP and 31 per cent of the population were against it. Immediately after Premier Chang announced suspension of the fourth NPP in 2001, six polls were conducted. The results of a poll carried out by *United Daily News* showed 56 per cent of the population was worried that the suspension of the fourth NPP would cause a power shortage in the near future. Only 22 per cent of the population believed Premier Chang's decision to suspend the fourth NPP would not cause a power shortage. The results also showed that the decision made by the Executive Yuan damaged the popularity of President Chen.

The poll results in *China Times* indicated that attitudes towards nuclear power depended on the level of education of the respondents. Sixty per cent of those with only primary education supported the decision of the Executive Yuan to terminate the project, while only 40 per cent of those with a higher education were against the decision. As shown in the results of a poll made by the DPP, under given conditions the termination of the fourth NPP would not cause a power shortage, and 58 per cent of the population supported the decision of the Executive Yuan to terminate the construction of the fourth NPP. A poll carried out by TVBS showed that 47 per cent of the population felt that the decision of the Executive Yuan was made based on the interests of the DPP. Only 31 per cent of the population thought that the decision was based on the interests of the public. As shown in the poll made by KMT, the public were worried that termination of the construction of the fourth NPP would cause: (1) a recession of the economy (33.4 per cent); (2) political instability (22.4 per cent); (3) an increase in the unemployment rate (11 per cent); (4) a negative impact on the stock market (8 per cent); and (5) a loss of competitiveness in the country (8 per cent).

After the Executive Yuan announced the resumption of construction of the fourth NPP, a poll carried out by *China Times* showed that 52 per cent of the population thought that members of the DPP should support the government decision, while 19 per cent suggested that members of the DPP should continue to fight for the termination of the construction. The poll conducted by the Environment Protection Quality Foundation showed that a narrow majority (52 per cent) thought that a public vote should be taken to determine the fate of the fourth NPP.

In short, the results of a range of polls demonstrate that about 40–60 per cent of the public supported the project while 20–40 per cent were against. In all polls, except that conducted by the DPP, there were always more people supporting the project than were against it. The margin was between 9–37 per cent. One major concern was whether other alternatives to the fourth NPP would be able to provide sufficient electricity needed for the continuing economic growth. The final disposal of nuclear waste was also an issue. Finally, a majority of people thought the public should have the right to make the final decision on the fate of the fourth NPP.

Promotion of 'A nuclear-free homeland' by the DPP's government

In a memorandum signed by the Executive Yuan and the Legislative Yuan to resume the construction of the fourth NPP, it was stated that 'A nuclear-free homeland' was the consensus among different political parties. When he announced the resumption of construction of the fourth NPP, Premier Chang also said that the first nuclear unit of Taipower would be closed down at the end of 2011. As required by the memorandum, the Executive Yuan had to propose an 'Energy Bill', addressing the issue. This bill was drafted by the Energy Commission of the Ministry of Economic Affairs. The name of the bill was 'The Law of Premature Closedown of the Existing NPPs'.

The first draft of 'The Law of Premature Closedown of the Existing NPPs' specified that three existing NPPs of Taipower would be closed down sequentially starting at the end of 2011, under the conditions that: (1) the reserve power on the electric grid would be no less than 15 per cent in the next seven years; (2) the increase in electricity demand in the next seven years is no more than 15 per cent; and (3) the closedown of the nuclear unit would not affect the national commitment to international agreements, especially in relation to climate change. It was also specified in the legislation that the government would allocate funds (1) to cover the deficiencies in the back-end foundations; (2) to make up the loss of Taipower; and (3) to compensate those employees who would lose their jobs due to the premature closedown, according to the relevant labour laws.

Taipower was obligated to write a report to address the above issues too. The report was reviewed by a special committee organised by the Ministry of Economic Affairs and members of the committee had the right to make the final decision on the premature closedown of NPPs. However, the Minister of Economic Affairs could veto the decision. If the decision of the committee was vetoed by the Minister, the committee members would have to reconsider their decision. If the members disagreed with the Minister a second time, the Minister of Economic Affairs had to follow the suggestion of the committee.

The first draft of the legislation was approved by the Ministry of Economic Affairs and sent to the Executive Yuan. After being reviewed by the Executive Yuan, it was sent to the Legislative Yuan for approval. However the bill has been sitting in the Legislative Yuan for a considerable time and has never been put on the agenda.

The Legislative Yuan did manage to pass the Basic Environment Act on 11 December 2002. In Article 23 of the Act, it states that: 'The government shall establish plans to gradually achieve the goal of becoming a nuclear-free country. The government will also strengthen nuclear safety management and control, protections against radiation, and the management of radioactive materials and monitoring of environmental radiation to safeguard the public from the dangers of radiation exposure.'

Finally, 'A nuclear-free homeland' became a major government policy. The Executive Yuan had organised the Nuclear Free Homeland Commission to consolidate and coordinate related issues. The Commission was composed of nine members from non-governmental sectors (including experts and scholars in fields such as law, economics and social sciences) and eight government officials representing the Executive Yuan's Atomic Energy Council, the Environmental Protection Administration, the Department of Health, the Ministry of Economic Affairs, the Ministry of the Interior, the Ministry of Education, the Ministry of Justice and the Government Information Office. The Commission drafted a strategic plan to implement the policy. The Commission is divided into eight workgroups, each responsible for specific nuclear-free implementation related matters. The eight workgroups are the Energy Structure Adjustment Workgroup, the Clean Energy Promotion Workgroup, the Nuclear Power Plant Phase-out Workgroup, the Nuclear Waste Management Workgroup, the Nuclear-Free Homeland Legislation Workgroup, the Fourth Nuclear Power Plant Monitoring Workgroup, the Nuclear-Free Homeland Promotion Workgroup and the Nuclear-Free Homeland Education Workgroup. After eight years of cultivation, 'A nuclear-free homeland' had finally become a slogan that resonates with the public.

The economic perspective of nuclear power

The relative cost of electricity generation from coal, gas and nuclear plants varies considerably depending on location. In general, nuclear power is cost-competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels. The generation costs from various types of fuels vary considerably. According to Taipower, in 2007 the cost of its coal-fired electricity was NT$1.18/kWh; it was NT$0.63 for nuclear, NT$2.57 for wind, NT$3.32 for combined cycle and the average generation cost is NT$1.79/kWh. The generation cost of nuclear power is significantly lower (35 per cent of the average and half of that of thermal generation) than other types in Taiwan predominantly because much of its energy sources are imported. For example, Taipower burned 53.5 million tonnes of coal and 10,377 Mega-M^3 of natural gas in 2005. For a country that relies heavily on imported energy, the transportation and storage of vast amounts of fossil fuel required for power generation are serious concerns in terms of national energy security. The energy released by the fission of 1 kilogram of uranium released in a typical reactor is equivalent to about 22,000 kilograms of coal. It is therefore quite common that an NPP stores the nuclear fuel required for the next fuel cycle on-site and a plant can be operated continuously at least for 18 months without having to change the fuel rods. Due to a lack of storage facilities, the reserves of liquefied natural gas (LNG) in Taiwan nowadays can last for no more than seven days. This means a great cost saving for nuclear power companies.

The construction cost of NPPs is high and fuel costs for nuclear power are only a minor portion of the total generating cost. Therefore, the impact of global energy price fluctuation on the generation cost of nuclear power will be relatively small. In Taiwan, the generation cost of coal increased from NT$0.83 in 2003 to NT$1.18/kWh in 2007, an increase of 42.2 per cent. The corresponding costs of purchasing fossil fuel for these two years are NT$87.0 and NT$188.6 billion, respectively, an increase of more than 200 per cent. This quantum jump is due to the price increase of fossil fuel that began in 2003–04. During the same period, the generation cost of nuclear power decreased by 1 NT cent due to an improvement of the capacity factor. The total amount of power produced by Taipower in 2003 and 2007 was 136.10 and 154.62 TWh, respectively, an increase of 13.6 per cent. Nuclear energy could at least stabilise, if not help lower, the average power generation cost.

Yet, there is high risk involved in building an NPP. Its intensive up-front capital investment means that it is subject to changes in interest rates, exchange rates, discount rates and macroeconomic conditions. Long delays in construction often add increased uncertainties to the cost of nuclear energy. The Lungmen nuclear power station of Taipower is a good example of an unexpected rise in costs with long delays and rescheduling.

Operating nuclear power units also involve financial risks. For example, the Niigata Chuetsu Offshore Earthquake that occurred on 16 July 2007 caused an emergency shutdown of all nuclear units of the Kashiwazaki Kariwa nuclear power station, a plant with seven units and installed capacity of 7,965 MWe. All units were successfully brought to a safe shutdown, but there was some minor leakage of radioactive material from the spent fuel pool and some minor fire hazards. The ground acceleration at the site during the earthquake exceeded the designed safety standards. Even though there was no damage to the plant components and, theoretically, the plant itself was safe to operate, all the units were idle for a long period after the earthquake. This resulted in a huge financial cost to the utility.

Because Taipower is a government-owned utility, the price of electricity is strictly regulated by the Executive Yuan. The electricity price is often used

Table 8.7 Profit before tax of Taipower

	2001	2002	2003	2004	2005	2006	2007
Billion NT$	23.67	31.31	31.76	8.47	1.23	–2.82	–31.24

Source: Taipower, 'Annual Reports', various years.

by the government as a policy vehicle to keep the inflation in a range that is considered acceptable by the public. Therefore, fluctuation of the global energy prices often is not translated into domestic electricity prices. In 2007, for example, Taipower had to absorb the losses of more than NT$100 billion just to keep the electricity price stable (Table 8.7).

Nuclear renaissance in Taiwan

Dr Ying Jeou Ma won the presidential election in March 2008 and KMT took over the government. The Executive Yuan of the newly elected government announced its Sustainable Energy Policy on 5 June 2008, which would promote the diversification of energy resources; increase the weighting of low-carbon energy in the energy portfolio; and keep nuclear power as a viable option for energy supply. The power generated from low-carbon primary energy resources would increase to about 55 per cent by 2025. The Ministry of Economic Affairs announced its Energy Security Strategy Plan on 28 August 2008. It specified that the government would expand renewable energy and nuclear power from a current 9 per cent to 18 per cent by 2025. The tentative goal for the CO_2 emission reduction is to the level of 2008 between 2016 and 2020, and to the level of 2000 by 2025.

Following these announcements, the government convened the 2009 National Energy Conference to solicit public opinions on the future of the government's energy policy. The Steering Committee of the conference decided the four main topics to be covered were: (1) sustainable development of energy security; (2) energy resource management and improvement of energy efficiency; (3) energy pricing and deregulation of the energy market; and (4) energy technology and industry development. Experts from research institutes and scholars from universities were invited to prepare the background information for the sub-topics of each group. The background information was presented at the conference to lead the discussion.

Between 19 February and 3 March 2009 regional conferences were held in the northern, central, southern and eastern parts of the county. They were open to the public and each conference lasted for two days. All four topics were discussed. The public responses and suggestions were recorded and documented. Then groups were formed to discuss the sub-topics and then closed-door meetings were held with only invited government officials, scholars from research institutes and universities, and representatives from non-governmental organisations. These group meetings were chaired by high-ranking government officials. Sometimes, cross-group meetings were organised too. In April 2009, a national energy conference was held to bring the delegates, responses and recommendations together. The Prime Minister Dr Chao-Shiuan Liu delivered a speech at the opening of the conference and attended the last session.

At the National Energy Conference, nuclear power was discussed and recommendations were presented:

- To extend the lives of the existing NPPs.
- To build six more nuclear reactors at existing sites and the first would be commercialised in 2020.
- To increase the share of nuclear energy in the total installed capacity to 20–25 per cent by 2025 and 30 per cent beyond 2025.
- To strengthen the public acceptance of nuclear power.
- To promote the safety of nuclear power operation through international cooperation.
- The government to be heavily involved in the identification of the repository site of low-level nuclear waste.
- To seek regional cooperation on spent fuel and high-level radioactive waste (HLW) management.

A number of concerns were also raised at the Conference. They include:

- Cross-generation justice regarding nuclear energy development.
- Safety concerns of nuclear energy development.
- Lack of trained engineers in operating NPPs.
- Lack of ability to manage nuclear wastes.
- Proper load management of NPPs.
- Costs of nuclear power.
- Government subsidies to nuclear energy.
- CO_2 emission from nuclear energy.
- Environmental consequences of nuclear energy.
- Renewable energy versus nuclear energy development.
- LNG as a better alternative to nuclear energy.

It seemed that at the end of the conferences, delegates, many of whom were anti-nuclear advocates, rejected all the recommendations made by group meetings on nuclear energy development. The newly elected government acknowledged the importance of nuclear power to the future economic development of the island. Taipower has developed concrete plans for nuclear energy expansion. A feasibility study is underway for a new NPP. According to Taipower, the total installed generation capacity of Taiwan will have to expand from the current 38.1 GW to 67.1 GW by 2025 to meet the rising demands. To ensure adequate energy supplies and to reduce greenhouse gas emissions; a portion of new power plants will have to be nuclear. For Taiwan, nuclear would be cheaper than LNG-fired generation capacity.

Despite these developments, the public remains sceptical about nuclear energy. Other major challenges include the following: to find innovative ways to raise the initial capital investment; to meet the environmental target set in the Basic Environment Act; to resolve disputes with anti-nuclear movements; and to formulate an acceptable policy on the management of nuclear spent fuel.

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9

Challenging Chernobyl's Legacy: Nuclear Power Policies in Europe, Russia and North America in the Early Twenty-First Century

Per Högselius

Introduction

The purpose of this chapter is to discuss the most important trends in nuclear power policies in the 'old' nuclear power states of Europe (including Eastern Europe and Russia) and North America, in order to put Asian developments in nuclear power policy into a broader context. The chapter starts out by briefly outlining the main features of the most dynamic period of nuclear expansion, starting in the mid-1960s and ending at the time of the Chernobyl disaster in 1986. The following section then discusses the political responses to this highly critical event, which led to a total stagnation in the expansion of nuclear energy. The main thrust of the chapter, however, is on the most recent trends in European and North American nuclear power policy. It discusses, in particular, the extent to and ways in which the 'Chernobyl legacy' is being overcome, and, if this is the case, whether this may pave the way for a new period of dynamism in the 'old' nuclear world. Sub-themes are the formal policies and strategies pursued by governments, the evolving actor landscape, investment policies and national capacities, and developments within the nuclear engineering industry. The last and concluding section summarises the findings.

Nuclear power before Chernobyl

Following the commercial breakthrough of light water reactor (LWR) technology in the mid-1960s, the world entered a period of intense construction in the nuclear sector, with a total of 423 reactors brought into operation in the period 1966–85 (IAEA 2008). Nuclear power became a major contributor to electricity production. The wave of exponential growth and expansion had been preceded by more than two decades of feverish research, development and experimental activities, which took place against a background of futuristic visions of nuclear technology as a 'generic' technology that was not only going to guarantee the world's energy supply for thousands of years, but also solve a variety of societal problems. Nuclear power was to be used not only for electricity generation, but also for heating, transportation, food conservation, space flight and in many other productive areas.

Regarding nuclear technology for energy production, uranium-based thermal reactor development was for a long time seen merely as the first stepping-stone towards a much greater effort to develop more advanced nuclear technologies. Fast breeder reactors, which could use the uranium fuel much more efficiently by 'breeding' fissile plutonium from the non-fissile U-238 isotope, were soon expected to replace the thermal reactors. These reactors were typically referred to as 'primitive' – before they were even commercialised! In those early days, breeder reactors were commonly referred to as 'second generation' reactors, whereas fusion reactors were thought to be the 'third generation' in nuclear engineering (Radkau 1983).

Some early commercial reactors had been in operation since the mid-1950s in the leading nuclear countries, which were mainly the world's nuclear weapons states. The 1960s saw the culmination of a struggle between different reactor designs and fuel choices, notably heavy water and light water moderated reactors that were to be fuelled by natural and enriched uranium, respectively. Several countries – such as Canada, Germany, France and Sweden – followed a heavy water, natural uranium-based nuclear strategy motivated by energy security considerations in terms of independence from foreign enrichment services and the option – not necessarily officially acknowledged – of combining heavy water reactors with weapons-plutonium production for nuclear arms.

The breakthrough of the American LWR technology as a comparatively cheap, simple and technically reliable reactor type, in combination with the emergence of a semi-free world market for uranium enrichment services, paved the way for a transition to light water technology in most countries. Large European nations such as Germany and France also mastered the enrichment technology on their own and could thereby embark on LWR programmes without compromising their security interests. Canada was the only Western country that continued to pursue a heavy water reactor (HWR) programme, and this made cooperation with Canada interesting for a number of developing countries.

Nuclear weapons ambition was the main driving force in developing reprocessing technology for separating out fissile plutonium (Högselius 2009). However, the dream of a civil nuclear future in which fast breeder reactors were expected to play the central role boosted the reprocessing developments considerably even at an early stage. The aim of developing a 'closed' nuclear fuel cycle in which both plutonium and depleted uranium were separated out, to be recycled in breeder reactors and in nuclear warheads, was further strengthened by the argument that the world's uranium resources might be limited. This argument must be viewed in the context of the expansive nuclear visions of the early nuclear era, when it was believed that nuclear power would and could take over virtually the entire energy sector. In the 1970s, the ambitions of governments in a variety of countries were still extreme in this respect, and the global demand for uranium was, accordingly, expected to skyrocket. In conjunction with the first oil crisis of 1973–74, the wave of expansion of thermal nuclear reactors (which took place in parallel with the oil crisis) gave way to enormous price increases in the uranium market, which seemed to confirm the necessity for economising on uranium as a scarce resource and consequently the need to invest in breeder and reprocessing technology.

At the same time, however, the nuclear industry faced a number of serious setbacks. Several nuclear accidents, as well as enormous technical problems, effectively put a brake on further developments. Had it not been for the two oil crises, it appears likely that the wave of nuclear expansion would have ended much earlier. Around 1967, breeder engineering faced a backlash because of a series of accidents and technical problems with developing efficient and secure cooling systems (Fjæstad 2010). In the early 1970s, a wave of accidents took place in reprocessing plants (Varchmin and Radkau 1981) and the nuclear power industry came under heavy public criticism for the first time.

In the late 1970s, several countries decided to abandon the more ambitious parts of their nuclear programmes, particularly breeder and reprocessing technology. This development was led by the USA. In 1977, President Carter issued a decree formally motivated by nuclear proliferation concerns but in reality responding to the enormous technical difficulties that had arisen with regard to breeder reactors and reprocessing. Sweden and Finland, two small but advanced European nations, also decided to switch to an 'open' nuclear fuel cycle without reprocessing and breeders. Austria abandoned its nuclear programme altogether in 1978, at a time when its first nuclear power plant was nearly complete. Several other small European countries that had not yet developed nuclear programmes, but which had made preparations to do so, shelved their nuclear plans.

Then, in 1979, the partial core meltdown at the Three Mile Island nuclear power plant near Harrisburg in the USA put a further brake on nuclear developments in the West. Finally, in 1986, the Chernobyl disaster in the Soviet Union became the ultimate breaking point for all further nuclear developments in Europe and North America.

Chernobyl's legacy

At the time of the Chernobyl accident in April 1986, the debate about the future of the nuclear industry was already well under way in many Western countries. Chernobyl delivered the final blow to almost all future plans for nuclear expansion in the developed world. Although the accident happened in the Soviet Union, which had a different type of institutional setting in the nuclear sector to that of the West, and reactors used at Chernobyl were outdated and did not resemble any Western-style reactor type, the public made little distinction and their outcry was intense. Most governments in the Western democracies found it politically impossible to continue their support for nuclear developments, and although there was a concrete prohibition against the construction of new reactors in only a few cases, nuclear operators felt that the long-term political risks involved were so great that any new investments were highly uncertain. Chernobyl also raised new demands for additional, expensive security measures and thereby served to extend the trend from the 1970s of rapidly rising costs for nuclear power plant construction.

Political developments were more radical in some countries than others. Countries such as Italy, Germany and Sweden decided (at different points in time) to decommission all their nuclear power and put a ban on new reactor construction. Italy was the first large country to actually decommission its entire nuclear capacity (the shutdowns were completed by 1990). In 1980, following the Three Mile Island incident, Sweden held a national referendum on the future of its nuclear power, which led to a parliamentary decision to decommission all nuclear power stations by 2010. In the years following the referendum, the political winds turned and it appeared that the decision might be reversed. But the Chernobyl accident reminded both the public and politicians of the reality of nuclear risks. The decision made in 1980 consequently remained the guiding principle.

In Germany, for a long while the Social Democrats and the Green Party pushed for a complete overhaul of the nuclear energy programme in the country without any success until 1998. The red-green coalition government was then able to push through the legislation of phasing out the country's nuclear energy programme.

Other countries also became much more hesitant to embrace nuclear power. Switzerland issued a ten-year moratorium on new nuclear constructions following a national referendum in 1990 (in which 55 per cent voted in favour of the moratorium). In Britain, the government issued a white paper in 1988, expressing its concerns over the costs of nuclear power, although it still saw nuclear energy as a necessary alternative source. Soon after, the Thatcher government launched electricity reforms with privatisation and deregulation in 1990–91. However, the government's initial privatisation strategy for the nuclear industry failed. In 1996, the government was eventually able to sell the most modern nuclear power plants, but it could not find a buyer for the obsolete Magnox stations. In the Netherlands, in 1994 the parliament decided to phase out its only nuclear reactor by 2003. In Belgium, which had one of Europe's most nuclear-intensive energy systems, the anti-nuclear movement started late. It was not until 2003 that a government decree prohibited the building of new nuclear power plants, while also limiting the lives of existing plants to 40 years.

The strong anti-nuclear sentiments in Western Europe following the Three Mile Island and Chernobyl accidents were accompanied by the 'reverse oil price shock', with falling oil prices during most of the 1980s and 1990s. When oil supply appeared less problematic, one of the strongest arguments for nuclear expansion lost much of its appeal. Nuclear energy development halted. In the 20-year period, 1966–85, the average number of new reactors which went in to construction worldwide was 21.2 a year (423 stations in total), while in the following 20 years (1986–2005), it was merely 3.6 per year (71 new constructions in total) – and only a few of these were in the 'old' nuclear power countries. Taking into account the substantial number of reactors that had been shut down during the same period, the overall number of reactors in commercial operation in Europe, Russia and North America declined by about 10 per cent from its peak in 1989, when 348 reactors were in commercial operation, to 318 in 2007 (Figure 9.1).

Ironically, regarding the public stance on nuclear power, the Chernobyl accident had less impact in the Soviet Union and Eastern Europe than in

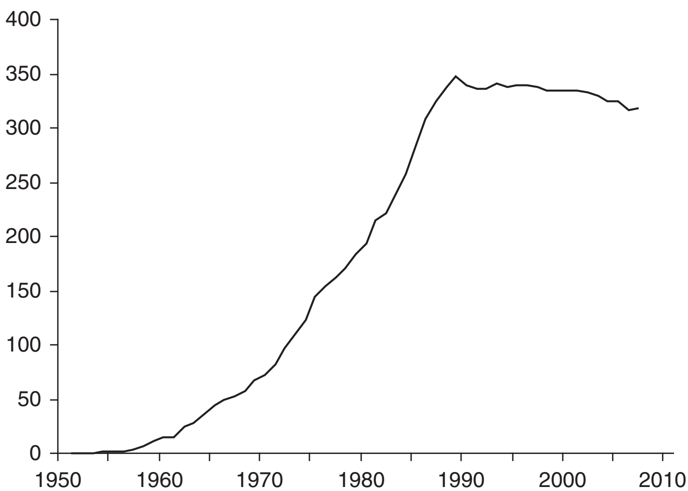

Figure 9.1 Number of nuclear power reactors in commercial operation in Europe, Russia and North America, 1950–2007
Source: Calculated from data in IAEA (2008).

Western Europe and North America. Gorbachev's 'glasnost' policy in the late 1980s led to the emergence of openly anti-nuclear movements, which had some impact. In most cases, however, these anti-nuclear movements – particularly in Lithuania, Armenia and the Ukraine – were in essence national liberation movements in Soviet republics that strove for national independence from Moscow (Dawson 1996). Overall, the public attitude to nuclear power after Chernobyl remained much more positive in Eastern Europe than in Western Europe.

Current trends in Europe and North America

Government policies and strategies

The last decade has seen significant changes in nuclear policies in both Europe and North America, possibly overcoming the Chernobyl legacy sketched above. A new commitment and support for nuclear energy can be discerned in formal government policies and strategies in an increasing number of countries. Governments that have shown the most support for nuclear energy are those of the USA, the UK, Finland, France and Russia, as well as several of the new European Union (EU) member states of Central and Eastern Europe. More careful in their nuclear policies are the governments of Germany, Sweden, Belgium, Spain and a few other European nations. However, even in these countries the broad underlying trend is now towards a more positive stance to nuclear energy. A notable development in this connection is that some of those countries that in the post-Chernobyl years decided to halt further nuclear expansion, or even decommission existing plants, have recently revised these decisions.

There are two factors that, more than any other, have served as arguments for shifting the anti-nuclear policies of the post-Chernobyl period in a more pro-nuclear direction: the first is *climate change* and the second is the problematic *dependence on imported fossil fuels*. Both factors can be thought of as being related to energy security, defined in a broad sense as involving three types of risk: environmental risk, supply risk and price risk (cf. Gupta 2008).

- *Environmental risks*. Since the 1970s, and in particular after Harrisburg and Chernobyl, nuclear power has appeared to involve enormous environmental risks, with a focus both on accident risks and environmental problems related to fuel cycle activities and radioactive waste management. Concerns about climate change, however, have shifted the environmental debate, and nuclear power is now considered cleaner than fossil fuels in ways that, in the view of many policy makers, outweigh the risks of nuclear accidents and potential radioactive leakages. This trend has gained momentum, particularly in Europe in recent years, with a common EU climate policy that involves binding commitments on reductions in CO_2 emissions. The member governments now must take concrete actions.

- *Supply risks*. There has been an increasing concern about supply-related risks, especially since the terrorist attacks in the USA in 2001 and in Madrid and London in 2004 and 2005, respectively. The main impact of these events on the nuclear sector has not been any radically increased fear of possible terrorist attacks on nuclear facilities, but rather a fear of over-dependence on imports of oil from the Middle East and other 'unfriendly' states. In Europe, the dependence on Russian natural gas has been a hotly debated issue for several years. The Iraq War and the political tensions between Iran and the West, and an internationally more ambitious Russian government under Putin and Medvedev, have stirred up considerable concerns of the reliability of oil and gas imports. Electricity production from domestic nuclear power stations has appeared more attractive from a security of supply perspective – although uranium mining, conversion and enrichment services are also areas where most countries are totally dependent on imports from abroad.
- *Price risks*. Volatile and rising oil prices in the world market since the late 1990s have certainly made nuclear energy more attractive. Even though uranium prices also rose dramatically to a peak level in 2007, this did not dampen the interest in nuclear energy expansion because the cost of producing nuclear electricity is not very sensitive to uranium prices.

All in all, in the recent round of political debate, nuclear energy has gained more popularity through what may be labelled a 'restructuring' in the relative interpretations of risks. Although nuclear energy may not be necessarily considered less risky today than 20 years ago, it is now being seen in a more favourable light relative to the risk interpretations of competing energy sources.

When discussing current European and North American nuclear power policies, it is important to emphasise the existence of the several hundred reactors that were constructed in the period up to the 1980s. Most of these will soon reach, or have already reached, their designated life expectancy. A major issue is, therefore, what will happen to these reactors and in particular whether they will be replaced by new nuclear reactors or by other energy facilities. Since new reactor construction involves substantial investment risks, an alternative has been to carry out far-reaching upgrades of existing reactors and expand their operating lives by 10–20 years or even longer. This strategy has also proved politically viable in countries whose governments are less pro-nuclear. The same goes for the trend to raise electricity output by way of more frequent fuel reloading and/or ambitious turbine improvements. In many cases, in so doing, nuclear power stations could increase their electricity production by 10 per cent or more – in Sweden the ambitious plan is to increase production by 20 per cent!

In Western Europe, only France and Finland have not been affected by the Chernobyl disasters to the extent to stop their nuclear programmes. Each currently has one new nuclear power reactor under construction. Finland now has four nuclear power reactors in operation and there seems to be a political consensus that the country needs additional nuclear projects to meet its electricity demand. Even the Green Party has reacted positively to the construction of the country's fifth nuclear power plant, which is scheduled to begin operation in 2013. The political support for new nuclear projects is built on the belief that nuclear operators can demonstrate a safe solution for handling spent nuclear fuel and radioactive waste. The country is also the first in the world to start construction of a deep repository for direct disposal of spent nuclear fuel (Kaijser and Högselius 2007).

France is unique in that it is the only large country with a near total dependence on nuclear power for its electricity supply (78 per cent). With 58 reactors in operation, France might play a key role in stimulating new nuclear construction elsewhere in Europe, since its leading nuclear operator, EdF, pursues a government-supported strategy of replacing all 58 reactors with around 40 new Generation III reactors. The construction for the first of these started at Flamanville in December 2007 and French President Sarkozy has recently confirmed his support for a second unit. However, this extremely ambitious project of totally replacing old nuclear reactors with new ones is conditional upon the successful completion of the Flamanville reactor, and the construction of this unit is currently experiencing severe delays. This is also the case with its sister reactor, which Finland has ordered from France and it should be noted that the nuclear engineering company Areva is currently making huge losses in Finland. Hence, it is still too early to say whether France's reliance on nuclear power will survive the planned grand transition to a new reactor generation. The situation is similar in Finland, which also aims to build a sixth reactor but where a failure with the fifth reactor would make it extremely difficult to realise another project.

Apart from Finland and France, the countries with a long-standing pro-nuclear stance include the former communist countries in Eastern Europe. Eastern European governments are, as a rule, positive towards nuclear power. This can be interpreted both in terms of the communist legacy – in the communist era, there was virtually no debate on nuclear power and in addition debates over nuclear waste issues were non-existent because spent nuclear fuel was being exported to the Soviet Union – and the sense of humiliation experienced in the new Eastern members of the EU following the forced nuclear decommissioning of old Soviet reactors (in Lithuania, Slovakia and Bulgaria).

The harsh EU policy towards East European nuclear power is unique in that it is the only case when foreign or supranational political actors have directly enforced a nuclear decommissioning process against the will of the country in question. The policy is comparable only to Western attempts to force Iran and North Korea to abandon their enrichment and reprocessing ambitions, respectively. The shutdown of several old Soviet reactors in Lithuania, Slovakia and Bulgaria – of which only the Lithuanian reactor is of the Chernobyl type – was set as a condition for EU accession of these countries, for which negotiations started in 1997. This EU policy was supported by the West European nuclear industry as an effective way of contrasting old Soviet nuclear technology with the more modern and arguably safer nuclear reactors developed in the West. However, the EU policy of forced decommissioning has strengthened rather than weakened the support for nuclear power in Eastern Europe, and many East European countries now wish to replace their Soviet-era nuclear capacities with new nuclear units.

Further east, Russia is a country with a long and legendary nuclear past and with a distinct nuclear vision for the future. Russia's formal energy strategy since 2003 has defined nuclear energy as a key component of its energy development and has expected that a substantial share of the increase in electricity consumption would come from nuclear power by 2020. More specifically, Russia set a target of *doubling* its installed nuclear capacity during this period (Energeticheskaya Strategiya 2003), which makes Russia unique among the 'old' nuclear power countries. No clear formal rationale is provided to back up this strategy, but it is generally considered that Russia wishes to increase the use of nuclear power as a way to economise on its valuable oil and gas resources, since these generate export income.

Russia also has a powerful nuclear lobby which includes hundreds of R&D institutes and strong links to the military. The nuclear community is behind the drive for, among other things, a clear commitment to a closed nuclear fuel cycle, with reprocessing as a key part of the industry (although in practice it remains at a very low level). Russia also sees its nuclear industry as an important potential export industry, particularly to non-Western countries (cf. Josephson 2005).

As mentioned earlier, there are a number of countries that have re-evaluated their sceptical stance towards nuclear power during the past few years and now fully support a strengthened role for nuclear energy. The USA saw a rise of governmental support for the nuclear industry during the Bush presidency. Having experienced one of the world's worst nuclear disasters in Harrisburg in 1979, and being strongly concerned – in the Carter tradition – with nuclear proliferation, the USA had a restrictive nuclear energy policy for many years. The Bush Administration, however, changed the country's official policy on nuclear energy and gave a green light for developing a closed nuclear fuel cycle, or at least for research on new reactor and fuel cycle technologies. The breakthrough for a new US nuclear policy was the Energy Policy Act 2005, which after long discussions passed through both the Senate and the House of Representatives with around 70 per cent support. The Act included support for nuclear development in the form of production tax credits, federal risk insurance (to cover regulatory delays), federal loan guarantees, nuclear liability protection (extended by 20 years) as well as support for advanced nuclear technology (WNA 2009a).

The Obama Administration has continued this new pro-nuclear direction. This pro-nuclear policy has support from both the Democratic and the Republican Party. During the presidential campaign in 2008, John McCain made quite clear that he was in favour of a massive increase in public subsidies to the nuclear industry (Romm 2008). The US Department of Energy (DOE) has also become very proactive in the internationalised fuel cycle and R&D activities, establishing the Generation IV Forum (GIF) and the Global Nuclear Energy Partnership (GNEP) as platforms for international cooperation among countries willing to embrace nuclear energy (see the discussion on nuclear engineering industry below).

The UK undertook a review of its energy policy at about the same time as the USA reviewed its policy, with Prime Minister Tony Blair arguing in November 2006 that the UK needed 'to put nuclear back on the agenda and at least replace the nuclear energy we will lose' (i.e. from plants that were to be decommissioned – all except one are to be closed by 2023). The pro-nuclear stance of the Labour government – which can be contrasted to social democratic anti-nuclear sentiments in countries such as Germany and Sweden – was strengthened under Prime Minister Gordon Brown, who in January 2008 confirmed the government's support for building new nuclear reactors. The pro-nuclear UK policy has remained in place after the new coalition government took office in May 2010, although new Energy Secretary Chris Huhne is a well-known critic of nuclear power.

In Italy, the announcement of a new nuclear expansion programme was among the first policy decisions of Silvio Berlusconi's new government when it took office in May 2008. The goal, now formally set, is for 25 per cent of the country's electricity to come from nuclear power by 2030 – up from 0 per cent at the present time! The Minister of Economic Development has spoken about the post-Chernobyl decommissioning of all nuclear power stations in Italy as a 'terrible mistake'. A problem in Italy, however, is that national politics is especially turbulent and it remains to be seen whether industry will rely on the new pro-nuclear stance of the government as a long-lasting commitment that can be embraced broadly by the chaotic parliamentary factions.

The Netherlands provides another example that the government reversed its previous decommissioning decision. The only nuclear reactor in the country was originally to be closed down in 2003, but the date was moved back to 2013, and in 2005 the phase-out decision was abandoned altogether. In 2006, the Dutch government signed a new contract with the nuclear operator to continue the operation of the plant to 2034. The Netherlands is a special case in Europe since it has access to large domestic natural gas deposits (discovered in 1959), effectively out-competing nuclear energy, politically speaking, as a dominant energy source. The gas fields are now on their way to becoming depleted, however, and the country is looking for new, complementary sources of energy.

There are also countries – Sweden, Germany, Belgium and Spain, for example – for which nuclear expansion seems improbable. There is an increase in support for nuclear power in some of these countries, notably Sweden and Germany, whose governments have recently reversed earlier phase-out decisions. But the continued political sensitivity of the nuclear issue means that, in practice, new reactor constructions seem unlikely. Spanish governmental policy is for a phase-out of all nuclear power by 2030, that is, when the existing reactors' operating lives run out (Romeo et al. 2009). In Belgium, too, the nuclear issue is still extremely sensitive. The 2003 decision (mentioned above) proposing the decommissioning of all reactors at the end of their operating lives is still valid.

Apart from the issue of whether or not to build new nuclear reactors, European and North American governments and policy makers are concerned with spent nuclear fuel and radioactive waste management. France and Russia are the only countries that have shown continued political commitment to reprocessing spent fuel. The UK, with its heavily criticised Sellafield facility, appears to be abandoning reprocessing, aiming instead for an open fuel cycle concept. The USA, on the other hand, is contemplating a re-entry into reprocessing, including the development of new radiochemical processes.

France, Britain and Russia have historically acted as recipients of spent nuclear fuel from other countries, to be reprocessed and returned, for example, in the form of MOX fuel. This trade continues, particularly with France, but the general trend is a decline in these transnational shipments, which are extremely sensitive from a political perspective, at least in Western democracies, given the plutonium handling and transport risks (Högselius 2009).

Of the countries embarking upon an open fuel cycle concept, with direct disposal of spent nuclear fuel, Finland and Sweden have advanced the most. Finland has, as mentioned above, already started the construction of a deep repository, and Sweden decided upon a site in June 2009. Historically, the siting of waste facilities has been a difficult topic in Western democracies, particularly at a time when the responsible authorities demanded that the 'best' location be used from a geological point of view. This has been referred to as a 'systematic' siting strategy and it led to preliminary geological investigations in municipalities that were concerned with the prospect of placing a 'nuclear waste dump' in their back yard.

In recent years, however, a transition from a systematic to a 'pragmatic' siting strategy has taken place, where the geological optimum is weighed against public acceptance (Kojo 2006). The authorities no longer necessarily demand that the geological conditions be 'ideal', but only that they meet certain specified minimum safety criteria. So far, in practice, this has led to nuclear waste facilities being sited in municipalities that already have nuclear power plants on their territory and which as a consequence usually regard nuclear power with pride and as a natural part of everyday life. Nuclear waste facilities are now increasingly being seen in a positive light from a local employment and economic development perspective (Sweden, Finland and Belgium are good examples).

The evolving actor landscape

In the past decade, energy security and climate change have been powerful ammunition used by *energy companies* that operate nuclear power plants to lobby governments for their support. For much of the post-Chernobyl era, the nuclear industry found itself in a difficult position, but as discussed earlier, most governments are becoming increasingly receptive to the nuclear industry's argument.

Today, a major difference compared with the last wave of nuclear expansion that occurred 30–40 years ago is that licensing procedures and environmental regulations are vastly more complex. This means a much longer process that a project has to go through, from getting the political endorsement to actual reactor construction. In this process, the public would be consulted to avoid future conflicts and political unrest. At the same time, with privatisation in the utility sector, the nuclear industry in many developed countries no longer operates with direct government instructions and its allocated resources. Consequently, private investors and privatised nuclear companies have become much more cautious in committing the resources in nuclear power projects not only because of the high economic risks involved, but also because of the fear of political changes of governments or changes in public attitudes, such as national elections that might suddenly result in a shift from a pro-nuclear to an anti-nuclear government, such as in Germany in 1998. Sweden is another example where uncertainty remains, in spite of government and public support for nuclear projects. In these countries, political risks involved might be considered too high for investors to invest in nuclear projects.

Energy companies are also hesitant to invest in nuclear power due to market risk. Nuclear power projects are not only capital intensive, but also take a long time to be constructed. In the process, a set of financial arrangements may be competitive when the project starts, but this may not be the case several years into the construction. There are risks related to exchange rates, to macroeconomic conditions, to the energy market situation and to unforeseeable new energy and environmental taxes. The industry has been reminded repeatedly of this turbulence through the dramatic oil and uranium price developments in recent years. The trend towards increasingly liberalised electricity markets, where price formation remains largely beyond a government's control, further contributes to a sense of uncertainty.

In the past two decades or so, the interest in nuclear energy from the *national defence* waned considerably in most Western countries, particularly in the smaller nuclear power nations that were once optimistic about combining civil nuclear power with nuclear weapons. In large countries that possess nuclear weapons, military interests now mostly pursue a separate development path (with dedicated plutonium production reactors and military-oriented reprocessing plants for the chemical extraction of weapons-grade plutonium). Hence, the overall trend has been towards a decoupling of civil from military interests. The situation in Russia is somewhat different because the links between the military and the civil parts of the nuclear sector are still significant.

However, even though the current links have weakened between nuclear weapons and civil nuclear programmes, it should be emphasised that the historical legacy of combined civil-military nuclear programmes continues to be clearly visible in the structure and organisation of the nuclear sectors in several countries. The most obvious expression of this phenomenon is that the European nuclear weapons countries (France, Russia, Britain) overlap with those pursuing nuclear reprocessing for civil purposes. Apart from this, the historically rooted military aspects of all nuclear engineering activities continue to be used in the public debate by anti-nuclear groups as an argument against civil nuclear power. Thus, although in practice military and civil nuclear activities are now largely separate from each other in most Western countries, there is a strong and arguably growing fear among the public that the acquisition of civil nuclear technology developed in the West might be used as a basis for developing military nuclear competencies in other parts of the world. The nuclear industry has responded to this concern about nuclear proliferation by setting out to develop 'proliferation-resistant' nuclear technologies (see the Section 'The development of the nuclear engineering industry'). There have also been attempts to create strictly regulated internationalised pools for uranium enrichment, with the aim to prevent new nuclear countries – such as Iran – from developing their own enrichment facilities, since these could potentially be used as a platform for military projects (Tollefson 2008).

The *anti-nuclear and environmental movements* form an important category of actors, although they differ markedly in strength and style between countries and regions. The German anti-nuclear movement is probably the strongest in the Western world and it has been instrumental in contributing to the paralysis that has characterized nuclear policy making in Germany.

Finland is a good counter-example, where the environmental movement has not principally been against nuclear power, but rather has acknowledged it as a domestic energy source while also taking an active part in shaping nuclear policy in a 'greener' direction (Kaijser and Högselius 2007). There are many examples of environmental groups in the West that have turned increasingly pro-nuclear in recent years. Still, European and American environmentalists generally do not accept the argument that nuclear power is needed to counter the climate threat. Instead, they favour renewable energy developments. There is frequently an economically motivated fear among environmentalists that nuclear expansion might take the resources away from the development of renewable energy.

Anti-nuclear movements have traditionally been represented by political parties with an agrarian profile and by parts of the social democracy movement. Agrarian parties tend to have a diverse agenda of which anti-nuclear is only one, partly because nuclear energy has long been associated with centralisation and large-scale industrialisation. Social democratic parties in Europe have developed a highly ambiguous position on nuclear power; on the one hand, their anti-nuclear stance is linked to the peace movement and to the women's movement, and, on the other hand, their strong links to industrial interests and labour unions in the energy sector often lead their support to specific nuclear projects. Since the late 1980s, anti-nuclear interests have also been represented in some countries by environmentally focused parties such as the Greens in Sweden and Germany.

Public acceptance of nuclear energy has been growing mostly in response to climate change issues and the concern of securing fossil fuels supplies. The public has, to a degree, accepted the nuclear industry's argument that nuclear power is needed to deal with climate change. In Sweden, young people today are more likely to be pro-nuclear than were young people of 20 to 30 years ago (Sandberg 2008). They do not quite share the previous generation's traumatic memories of Harrisburg and Chernobyl and some of them have never even heard of the disasters. In the USA, the opposite seems to be the case: Greenberg in his study has shown that only 33 per cent of those under the age of 35 supported the nuclear energy expansion in comparison with 52 per cent of the people surveyed in general and 63 per cent of the people in the age group of 65+ (Greenberg 2009).

Investment policies and national capacities

Historically, investments in nuclear power in Europe and North America were motivated to build a strong national capacity in nuclear engineering. A competent nuclear engineering capacity was seen as crucial, particularly because nuclear technology was considered as a 'generic' future technology that was crucial for the national interest.

Today, such links between nuclear investments and long-term state interests are no longer particularly strong. Following the trend towards neoliberalism in Western politics since the 1980s, governments have become much more reluctant to be directly involved in nuclear projects. Several governments have openly declared that they will 'leave it to the market' to decide whether or not (and what type of) new nuclear units should be built. With increasingly liberalised electricity markets, many countries no longer regard it as acceptable that their government would favour any particular energy technology as long as it meets the regulatory demands as codified in laws and rules; the trend is towards a technology-neutral investment policy. The influence of governments on energy developments has accordingly become much more indirect. Hence, whereas some governments now openly support new nuclear projects in the overall energy debate, they are often both unable and unwilling to directly support concrete projects. This is the case, for example, in Britain. Sweden is also a country where a similar stance seems to be emerging.

There is some correlation between countries that pursue new reactor construction and those where the state is in (direct or indirect) control of the nuclear sector – notably France and Russia. Finland is also pursuing new reactor construction, without any far-reaching state ownership. There has, nonetheless, been a long-held national consensus with a strong political backing in favour of nuclear energy. A further contributing factor is that the new Finnish reactor is owned by those industrial companies that will use its electricity output, creating a situation where the energy has been pre-contracted for a long period in advance.

Another way to seek stable conditions for investments – and lower risks – has been through internationalised pooling of financial resources in the form of a joint participation of energy companies from several countries in new nuclear reactor projects. This is in stark contrast to the historically perceived importance of national independence in energy in general and in nuclear projects in particular. This is a result of increased turbulence and uncertainty in Western energy and nuclear policy developments – giving rise to shorter planning horizons – and the enormous costs of new reactor projects, which is to a large extent the result of high environmental and safety demands (Romm 2008). The new French 'European' pressurised water reactor (EPR) that is being built at Flamanville, for example, will cost €3.55 billion (in 2008 prices) and the corresponding expenditure for constructing the Finnish EPR project is about the same, €3.2 billion (in 2003 prices). The project under construction at Flamanville is financed not only by Areva and EdF, but also by the Italian energy company ENEL, which has a 12.5 per cent stake in the project. This arrangement is expected to become a long-term form of cooperation and risk sharing for construction and operation of expansive nuclear power plants. A similar pattern of financing is expected if Italy decided to build a nuclear power plant. A further international project is based on the idea to replace Lithuania's Chernobyl-type reactors with one or two modern Generation III reactors. Several neighbouring countries are involved in this project, all of whom expect to get a corresponding share of the electricity to be produced in the new plant.

In addition to multinational ownership of new nuclear power projects, there has been an increasing trend of multinational ownership of existing nuclear power plants. This is becoming a trend in Europe because of the far-reaching internationalisation of the European electricity industry. The Swedish state-owned company Vattenfall, for example, now owns nuclear capacity in Germany, Finnish-owned Fortum owns capacity in Sweden, Italian company ENEL owns a large share of nuclear plants in Spain and Slovakia, Germany's large energy company, RWE AG, owns nuclear capacity in Britain and the French EdF company will probably take over some reactors in the USA. Such developments would have been inconceivable two or three decades ago.

In Eastern Europe, incoming foreign investment is regarded as a possible solution for several countries that want to replace the existing nuclear power plants with new types of reactors. These countries are financially too weak to be able to fund these new projects on their own. These financial limitations – which include both state and private actors – have become even more pronounced following the global financial crisis (starting in 2008), which hit many Eastern European countries particularly hard. Foreign investment may be the only option for these countries if they want to have new nuclear power projects. Meanwhile, foreign investment in Eastern European nuclear power remains a sensitive issue for both investors and the public in these countries. Consequently, the most important investment trend in these nations seems to be towards an extension of reactor operating lives and the expansion of turbine capacity.

The trend towards the extension of reactor operating lives and the expansion of turbine capacity is also common in Western Europe and North America. In countries where the nuclear issue remains highly sensitive, nuclear operators have found that the only acceptable way of expanding nuclear energy is to increase the effects and operating lives of already existing reactors. Sweden, for example, despite having shut down (for political reasons) two of its original 12 reactors, actually has a much larger nuclear capacity than ever before, thanks to improvements to existing reactors.

The development of the nuclear engineering industry

The post-Chernobyl stagnation in nuclear power developments had far-reaching effects, not only for energy companies but also for the nuclear engineering industry and the R&D community. Because of the stagnation, they faced a market that had collapsed for much of their goods and services.

In the nuclear engineering industry, the post-Chernobyl period saw a trend towards market concentration. Reactor producers, most of which were already large firms, went through a wave of mergers and acquisitions, seeking synergies and economies of scale as a way to cut costs. In the reactor business, a few large multinational companies are now totally dominant. They are formed on the basis of firms that, until recently, were intimately linked to vital interests of national security. International technological dependencies in the supply of components and services of various kinds have thereby increased.

For example, the reactor producers of Germany and France (Siemens/Kraftwerk Union and Framatome, respectively) decided in the early 1990s to pursue jointly the development of their new Generation III reactor type, dubbed the 'European pressurised water reactor'. This project-based development cooperation was followed in 2001 by a merger of most German and French nuclear operations, forming a powerful, France-based actor that since 2006 is known as Areva Nuclear Power (Areva NP), and in which Siemens held 34 per cent. In January 2009, however, Siemens's supervisory board declared that they intended to sell their stake in the company (Siemens 2009a). Shortly after, it was announced that Siemens and the Russian nuclear giant Rosatom had signed a Memorandum of Understanding for the creation of a joint venture, aimed primarily at the further development of the Russian VVER technology (Siemens 2009b).

The national pride of America's nuclear reactor business, Westinghouse, was fully acquired in 1999 by the state-owned British Nuclear Fuels Limited (BNFL), which was in charge of nuclear fuel cycle activities and operation and decommissioning of the country's obsolete Magnox reactors (which the government did not manage to privatise along with the more modern reactors in 1996). A year later, BNFL also acquired ABB's nuclear operations, which were deeply rooted in Sweden's nuclear history, having built a dozen reactors for Swedish and Finnish nuclear power plants. BNFL, however, in turn sold both ABB's and Westinghouse's nuclear operations to Toshiba in 2006, along with an array of British nuclear operations, hence removing BNFL as an independent actor in the global nuclear engineering industry. Hence, both Germany and Britain have now largely stepped out of the nuclear engineering business.

Consequently, much of the European and American nuclear engineering industry is currently in the hands of French and Japanese firms. An interesting exception to this pattern is the Canadian nuclear giant, Atomic Energy of Canada Limited (AECL), which has remained a relatively independent and dynamic nuclear engineering company. AECL has a long track record on the export side, having exported nuclear reactors to Romania, Argentina, India, South Korea and China – mainly regions where nuclear energy is currently expanding. Historically, this is based on AECL's HWR technology, which, as discussed above, has been an attractive choice in many developing countries for national security reasons. Even AECL, however, is being globalised in response to the enormous cost pressure, and international dependencies are considerable. Thus, the company's new advanced CANDU reactor design, for example, will include a scheme with 'major components built in US shipyards' (WNA 2009b).

It has become more difficult to discern what is indigenous and what is foreign technology. The business has undergone a rapid process of globalisation and few countries today are even close to being technologically independent in designing and manufacturing critical components – the two notable exceptions being France and Canada. This is a logical consequence of the extreme pressure for cost effectiveness in a stagnating industry.

In parallel with the radical restructuring and globalisation of the nuclear engineering industry, however, the new pro-nuclear policy trends described earlier in this chapter have stimulated a fresh optimism in innovation and technological development. For many years following the Chernobyl disaster, innovation activities stagnated along with the industry as a whole. This has endangered competence building for the future, with many countries feeling concerned about ensuring a continuity of educated nuclear researchers and engineers.

The problem has been most severe in countries that operate a large number of nuclear power plants but which have already decided to shut them down for the long term. In these countries, the study of nuclear engineering has not been seen as a reliable career choice for their young generations. The more recent trend, however, seems to be reversing this negative development, and both education and research in the nuclear field are expanding again.

The USA and Russia, the former superpowers, have been particularly active in promoting nuclear R&D. Their policies are linked in part to efforts to respond to the demands for effective fuel cycle activities (particularly the waste issue) and partly to the argument that many nuclear reactors are ageing and will have to be replaced by more modern reactor types. Russia is pursuing an aggressive policy for the export of nuclear goods and services to non-Western countries, and the nuclear engineering complex is arguably one of the few hi-tech sectors in which Russia – whose economy is heavily based on natural resources – may have an impact in the global market.

The USA has taken the initiative with two major internationally oriented R&D programmes: the Generation IV Forum (GIF) and the Global Nuclear Energy Partnership (GNEP). GIF was established in 2000 by the US Department of Defence as an international platform for cooperation and focuses mainly on new advanced reactor designs, to be employed from around 2030. By late 2007, 12 countries and Euratom had signed the GIF Charter (GIF 2008). GNEP was launched by the USA in 2006 and focuses more on the fuel cycle. Both programmes are reminiscent of the spirit of the 1950s, in the sense that they are extremely optimistic about the future prospects for nuclear power expansion globally. In the official argumentation regarding GNEP, non-proliferation concerns constitute a main driving force behind the establishment of the programme, the main aim being to develop 'proliferation-resistant' reprocessing technologies. Spent nuclear fuel, according to the GNEP vision, would be reprocessed 'without separating out pure plutonium' (GNEP 2007). It is thus an attempt to challenge the dominant view that reprocessing is inevitably linked to the dangers of nuclear proliferation. Obviously, however, both GIF and GNEP must also be seen in relation to the US nuclear community's lobbying efforts to revive nuclear power R&D in general.

Conclusion: prospects for nuclear expansion

This chapter has shown that the early part of the twenty-first century has seen a significant rise in interest in nuclear power policies in Europe, Russia and North America. This change may indicate the possibility that the 'Chernobyl legacy' might be overcome, possibly paving the way for a new period of nuclear dynamism among the 'old' nuclear power nations. Meanwhile, this change has not been translated into actual nuclear plant construction. It remains difficult to predict whether the new emerging policies will ultimately have a large-scale impact on the industry. IAEA statistics show that a total of 25 new commercial nuclear units went into construction between 2004 and 2008, of which only 2 were in Western Europe and none were in North America, 3 were in Russia and 20 in Asia. These figures show that nuclear energy expansion in the twenty-first century may indeed be an Asian development, with an average of four new reactors commencing their construction each year. This development in Asia, however, is still far below the enormous construction boom that took place among the 'old' nuclear power countries during the 1970s and 1980s, when construction started on an average of 25–30 new reactors *annually*.

The fate of the Western nuclear industry will most probably be decided by the ways in which governments, utilities and the nuclear industry choose to deal with the many reactors that are now quickly approaching the end of their operating lives. Hundreds of reactors must be replaced within the next 10 to 20 years if nuclear power is to remain an energy source of any significance in Europe and North America. Some analysts think that the industry – given the enormous investment required, long construction time and political risks involved – will not be able to have a quick expansion even if governments adopt pro-nuclear policies. Consequently, the nuclear energy industry in many countries may simply disappear gradually. There are some indications that the nuclear industry has become ever more concentrated and nuclear conglomerates in engineering, fuel services and in operation and management of nuclear power plants from Europe and North America are already preparing for a global shift towards Asia.

In the medium term, the trend in the 'old' nuclear power countries is towards an extension of reactor operating lives and an expansion of turbine capacity. Such a development, with the nuclear industry only staying alive thanks to the momentum of past achievements, is considered less risky from an investment perspective – though not necessarily from an environmental perspective – and it is seen as politically acceptable in most countries.

Further developments in the policy field will also depend on how the industry and the responsible authorities manage the nuclear fuel cycle and, in particular, nuclear waste management. This in turn depends on both the public acceptance of nuclear waste facilities and on geological and technological developments in the field. A revival of reprocessing has recently been expressed as desirable in some countries, but in practice the reprocessing industry is stagnating. Moreover, the extremely ambitious technological plans for the fuel cycle, as outlined in major American and Russian nuclear programmes, appear to belong to the distant future in terms of their actual realization. They will therefore not have any strong impact on commercial-scale developments within the next 10–20 years. In the meantime, it appears more likely that with the development of more advanced renewable energy technologies, renewable energy will be the future in many European countries. Regardless, the impact of nuclear power policies on industry developments must be analysed in relation to the overall dynamism in the energy sector as a whole, which is both turbulent and complex.

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10

Implications for Australia as a Supplier of Uranium to the Asian Region

Stuart Harris

Introduction

Significant interest in Australia's uranium export industry has re-emerged relatively recently and on a broader front than before. This reflects expectations of uranium demand growth in the face of increased energy demand, fears of eventual reduced supplies of traditional energy sources, further evidence of global climate change and prospective higher electricity prices that would make nuclear energy more economic. This chapter looks at how Australia is responding to that renewed interest and how it seeks to balance its economic and environmental interests against the implications for its traditional nuclear non-proliferation activism.

For some time, Australia has been globally exporting uranium oxide, or yellowcake, for nuclear power production including, in the Asian region, to Japan, South Korea and Taiwan; it recently made its first shipments to China. Interest in Australian uranium has also emerged in India, Indonesia and the Philippines as these nations move to expand further, or to develop, nuclear power generation. There have also been signs that other regional states, including Vietnam, Malaysia and Thailand, each of which has research reactors, have interests to varying degrees in developing nuclear power for electricity generation. That international interest in nuclear energy extends beyond just questions of commercial access to fuels but to the security of that access. For uranium, as demand grows, and energy supply tightens, security of supply has become an important factor in policy decisions.[1]

The implications for Australia as a supplier of uranium to the region, beyond the immediate economic benefits, are substantial. In part, their significance will depend upon the conditions under which exports take place and the form that the uranium takes when exported. Although uranium is most likely to continue to be exported in the form of yellowcake, the export of uranium in association with copper ore or other mineral ores is an additional minor complexity. More important is the development of the nuclear cycle in the region and the related question of the supply of enriched uranium. For Australia, therefore, the implications as a supplier of uranium will depend significantly upon the continuing effective operation of the international nuclear non-proliferation regime. That this may be in some doubt is discussed below.

Australia first mined uranium commercially in the early 1950s, for the US and UK nuclear weapons programmes. The early history of the industry in Australia was of a uranium export industry based on uranium discoveries in the 1970s in South Australia, Queensland and the Northern Territory. The industry is now thought to have 25 per cent of the world's reserves and close to 40 per cent of the world's low-cost reserves.

Export controls fall within the jurisdiction of the federal government. With respect to exporting uranium, the policies of federal governments of the day have varied considerably as attitudes evolved, not just as political control of government has changed; party policies have themselves gone through significant rethinking and adjustment over time. The related policies of the Australian Labor Party (ALP) at the federal level of government have changed substantially over the post-World War II decades; but so, too, have those of the Coalition parties (conservative Liberal and National parties). In the context of the immediate post-World War II (WWII) Australia–UK nuclear collaboration, and the then emerging global nuclear threat of the Cold War, the Labor Party under Ben Chifley toyed with the idea of nuclear weapons development and the subsequent Coalition government moved more clearly towards such a development in the name of 'Imperial Defence', later reinforced by China's testing of a nuclear weapon in 1964. The impetus fell away as bilateral relations with the USA developed (Reynolds 1998). It was finally swept away by Gough Whitlam when he became prime minister in 1972.

The ALP had originally supported uranium mining and the development of a domestic enrichment and nuclear power industry. The idea of exporting uranium, however, had run into a growing public opposition to nuclear energy, concern for preservation of Aboriginal lands and broader environmental issues, and hostility to French nuclear tests in the Pacific. The ALP government had initiated an inquiry, the Ranger Inquiry, to look at the environmental issues associated with any mining for uranium in the Northern Territory. Subsequently the ALP policy changed after the ALP lost office in 1975. The new policy was that mining uranium and developing a nuclear industry was to be opposed when the Party returned to office.

When the Ranger Inquiry presented its report, it was to the incoming Coalition government. The Ranger Inquiry's report supported the export of uranium but under rigorous conditions, both internationally as well as domestically (1976). The Coalition government, arguing the contribution of exports in strengthening the global non-proliferation regime, accepted the Ranger Inquiry's recommendations and agreed to uranium exports from the Ranger mine in the Northern Territory provided strict safeguard agreements were in place (Indyk 1980: 128). Exports began again in 1977. The government of the day, under Prime Minister Malcolm Fraser, followed the Inquiry's recommendation and adopted systems of bilateral safeguards with International Atomic Energy Agency (IAEA) verification.

Thus, by 1982 when the ALP returned to office, uranium mining was well underway and the Party revised its policy. Mining was now to be restricted to the two established mines but exports of uranium were also permitted where uranium was mined incidentally to the mining of other minerals; the 'Roxby Downs' amendment to the policy allowed Olympic Dam – a major copper and uranium development – to proceed. Hence, the so-called 'three mines' policy was adopted – for Ranger, Narbalek and Olympic Dam mines – and this eventually became the 'no new mines' policy to accommodate the closure of Narbalek in 1988 and the start up of Beverley that took place under the Coalition in 2000.

The expected substantial returns from uranium exports failed to materialise for most of the 1980s and 1990s. The main reasons for this were the static market, and because uranium prices were low, partly as a consequence of Australian output expansion and partly resulting – with the end of the Cold War – in the disposal of secondary uranium from reductions in military stocks by the major powers adding substantially to supply. Consequently, for many years uranium mining was not highly profitable. This did not change until the upturn in energy prices in the early part of the twenty-first century and as global climate change emerged as a political issue. The lessons of exaggerated uranium market expectations may not be irrelevant today.

A sizeable public opposition to mining remained and, although bipartisanship continued on safeguards and non-proliferation issues until recent years, the ideological differences of the political parties were important. The different attitudes to uranium mining continued as a bone of contention between the ALP and the Coalition until 2007 when the ALP policy to block new uranium mines was abandoned.

Despite the Coalition's support for the expansion of mining, and although the federal government has power over exports under the Australian Constitution, the state governments have the effective powers to license mining. Until recently, the state Labor governments have been able to block the expansion of the number of uranium mines. Opposition in some states was gradually eroding, however, and this helped change the Labor Party policy. Now the federal minister responsible believes Australia should increase uranium mining and exports to meet the increased demand for uranium in China and presumably elsewhere (Hayes 2009).

There are now three mines producing uranium: Ranger in the Northern Territory and Olympic Dam and Beverley in South Australia. They now supply 20–25 per cent of the world market. BHP Billiton is moving to open a new mine, Yeelirrie, in Western Australia and Honeymoon will soon begin producing in South Australia. Within a few years, these two additional mines alone will provide an increase of some 50 per cent of the current annual production of around 10,000 tonnes. Further commercial deposits of uranium have been found in the Northern Territory, South Australia, Western Australia and Queensland; the Queensland State Labor government, however, has not yet agreed to license uranium mining.

Among the factors leading to the Labor Party's change of mind has been the recognition of the greater international interest in the development of nuclear power, with the consequent economic benefits and the positive effects on limiting greenhouse gas emissions. That recognition, however, has also presented the Labor Party with a predicament: how can it influence how that development takes place in order to minimise nuclear proliferation globally and more particularly in the region where weapons proliferation may be a less likely problem than nuclear safety and the safeguarding of nuclear materials?

When in government, the Labor Party made efforts to reduce the risks of nuclear proliferation and conflict have been long-standing, as illustrated by its efforts in developing the Comprehensive Test Ban Treaty (CTBT), in pursuing a Nuclear Weapon Free Zone in the South Pacific (Treaty of Raratonga 1986), in setting up the Canberra Commission on the Elimination of Nuclear Weapons (Canberra Commission) established by the Labor government when previously in power and which reported in 1996, initiating the International Commission on Nuclear Non-Proliferation and Disarmament (International Commission) co-chaired by Australia and Japan, and now the Inquiry into Nuclear Non-Proliferation and Disarmament, by the Joint Standing Committee on Treaties of the Australian Parliament.

Australia's international policies on environmental/safety and non-proliferation/security policies

Safeguards and non-proliferation

Although Australia has a clear economic interest as a major exporter of uranium oxide, it is fully cognisant of the strategic and environmental significance of the commodity. Consequently, special measures have to be put in place to deal with uranium internationally, notably to distinguish military from non-military applications and to ensure Australian uranium is used only for peaceful purposes.

Since the adoption of the recommendations on safeguards of the Ranger Inquiry, there has been a bipartisan approach to safeguards by both Coalition and Labor Party governments that has no doubt made uranium mining more palatable to the community. Australia, described by Jeffrey Lantis as 'a global champion of non-proliferation' (Lantis 2008), has been conscious of the need to sign bilateral safeguard agreements with countries to which it sells uranium. It wants to sell uranium only to countries that are signatories to the Nuclear Non-Proliferation Treaty (NPT), have a bilateral safeguards arrangement under it and, since its adoption, have subscribed to the IAEA's 1997 Additional Protocol to Nuclear Safeguards Agreements, which provides for strengthened safeguards. Australia has also been assisting those Asian states that have signed the protocol on its practical implication to facilitate early ratification.

Australia now has 22 nuclear safeguard agreements in force covering 39 countries and also Taiwan. Six of those agreements – with Japan, China, Korea, the Philippines, New Zealand and Taiwan (via an agreement with the USA) – relate to importers in the region. These agreements place obligations on the bilateral partner regarding Australian Obligated Nuclear Material that apply to uranium as it moves through the different stages of the nuclear fuel cycle (DFAT).

For the credibility of Australia's safeguards, IAEA verification is an essential component. Australia is one of the few developed countries without a nuclear power industry, but as a major uranium supplier, it has been an active participant in IAEA Executive Board discussions on the development of safeguards. In the face of widespread global criticism, echoed in Australia, that the 'full scope' safeguards were not adequate to detect the clandestine acquisition or weaponisation of nuclear material, it played a constructive role in developing and encouraging the adoption of the IAEA's Additional Protocol to Nuclear Safeguards Agreements. As already noted, this has now become a further precondition for Australia's exports of uranium to non-nuclear weapons states (NNWS).

The international safeguards regime and the Australian bilateral safeguards pursued under it are controversial in Australia. Critics doubt their overall adequacy and reliability. Public attention has tended to focus particularly on sales to nuclear weapons states (NWS). Australia has been a substantial exporter of uranium to the NWS – notably the USA, the UK and France – but when more recently the safeguard agreement with China was signed, it elicited some domestic controversy, as did the agreement with Russia.

Nevertheless, the problem with uranium exports to NWS is that, as Richard Leaver notes, they are regarded by the IAEA as horses that have already bolted and therefore it is not interested in using its scarce resources for safeguards or verification of their civil nuclear activities (Leaver 2009). NWS are not obligated to accept safeguards arrangements, although now all have done so on a voluntary basis; they offer a list of civilian plants open to the IAEA to inspect and from which it can choose. The Additional Protocol, which China and a number of Asian countries have signed, gives the IAEA scope for challenging inspections for those countries that have signed it, although how much of an assurance that provides in practice is unclear.

The basic principle underlying the safeguards has itself been criticised in that, despite the claims that Australian uranium will not be used for weapons production, it is seen to make little difference if it acts as a substitute for uranium sourced elsewhere and that is thereby released for weapons production. The safeguards process has been undermined by the IAEA's move to Integrated Safeguards as an economy measure, the increased costs of the Additional Protocol, and the financial constraints imposed by the USA, Australia and others on the IAEA budget.

There is also a more general concern that the move by the IAEA to Integrated Safeguards as an economy measure under tight financial constraints imposed by the USA, Australia and others on the IAEA budget and the increased costs of the Additional Protocol has weakened the safeguards process. This is not necessarily the case as a Canadian study, although on a small and not particularly representative sample, has argued (Boureston and Feldman 2007).

Moreover, the bilateral agreement with China is currently being renegotiated to facilitate a major mine expansion at Roxby Downs in South Australia for exports to China of uranium infused copper concentrate to ensure that any uranium extracted would be satisfactorily accounted for and become subject to the monitoring of the safeguards agreement. Leaver questions whether the Chinese safeguards are more about form than about substance (Leaver 2009).

For NNWS, in particular, the critiques question the adequacy of the monitoring process. For them, the problem is that insufficient account is taken in the safeguarding process of the capacity for reactor grade uranium to be made into weapons. A further argument relates to the 'back end' of the cycle. The expansion of nuclear power would require an increase in production of large amounts of reactor grade plutonium that could be reprocessed for weapons production. These are contested issues, but while debate continues over the ability to make weapons from reactor grade uranium and from reactor grade plutonium, some strong voices suggest this is possible and may already have happened (Belac 2009; Garwin 2009). There is also a view that existing safeguards do not take sufficiently into account the concerns that terrorists might be able to gain access to fissile material, despite that the IAEA has taken a number of steps since 1970 for the protection of nuclear materials. These steps include, most recently, the 2002 Action Plan for Protection Against Nuclear Terrorism.

Australia will no doubt put forward constructive ideas in the 2010 NPT review context on improved safeguards.

The NPT bargain

The foregoing discussion needs to be seen in a context in which Australia now faces a potential conflict of objectives in its uranium export and nuclear non-proliferation policies. How it will seek to resolve this conflict is yet to be spelled out by the government. A primary objective of the International Commission is to reinvigorate the global debate on nuclear issues and another consideration is how to strengthen the NPT; but it will no doubt also give advice to the Australian government on its approach to the 2010 NPT Review Conference. As well, the Australian Joint Standing Committee on Treaties will presumably make a contribution to the policy thinking about the NPT review.

Australia's potential conflicts with the NPT review may come from its realisation that in expanding uranium exports to gain economic and global climate change benefits, it might risk the possibility of proliferation of nuclear weapons. Expansion of nuclear energy programmes in the region will add to the number of plants using and producing fissile materials and to a greater spread of nuclear expertise and technology. Despite the acknowledged failures in the safeguards and verification processes, notably in Iraq in 1991, the management of the nuclear processes can be argued to have been reasonably successful as far as the first of the three pillars of that mechanism is concerned – proliferation – although, as we discuss below, not all agree with that proposition.

Australia's position has been that both NWS and NNWS had obligations under the NPT regime and that the reduction of nuclear weapons was a critical component of maintaining the non-proliferation regime. Consequently, Australia has been conscious of the bargain represented by the two other pillars – the commitment of NWS to move towards disarmament, on the one hand, and, on the other, the rights of the NNWS to have available to them the benefits of peaceful nuclear energy while forgoing the nuclear weapons option.

Australia has long interpreted this bargain as involving an active role in meeting the obligations implied in the rights of the NNWS. The Ranger Inquiry had said that if Australia declined to export uranium it would be in breach of its obligations under Article IV of the NPT to NNWS that were parties to the NPT (Clark 2008: 312). As noted earlier, Australia has been an active participant in the international debate over the nuclear cycle at all levels. The Fraser and Hawke governments both stressed the critical management issues of the nuclear cycle and there was substantial bipartisanship over the need to set examples and stress discipline in the safeguarding of material in the civilian nuclear fuel cycle while seeking more effective ways of limiting nuclear weapons proliferation.

Australia has actively participated in the debate in the international community on nuclear issues in general and nuclear proliferation in particular. It has sought to take a lead in contributing to the international debate and was active in supporting the continuing renewal of the NPT and gaining support, including through pressing for a CTBT, for the 1995 indefinite extension of the NPT. As part of the continuing activism in the field of non-proliferation and nuclear disarmament, under the leadership of the Hawke government appointed Ambassador for Disarmament, Australia's efforts to achieve a ban on nuclear weapons testing, although opposed by the USA, contributed ultimately to the passage of the CTBT.

Although the CTBT was passed by the United Nations (UN) in the early days of his government, Howard made little diplomatic effort in seeking support for its ratification. The Coalition government focused all its attention to strengthening its ties with the USA and accepting the lead of the George W. Bush Administration. Nor did the Coalition show any enthusiasm in seeking a follow-up to the 1996 Report of the Canberra Commission.

At the 2000 NPT Review Conference, the NWS agreed on a 13-point programme of nuclear disarmament action. Upon taking office in 2001, the Bush Administration did not support this programme (Huisken 2009). Some elements of the programme were implemented anyway, such as the moratorium on nuclear weapons testing, but they were only a few, hence the lack of agreement at the 2005 Review conference.

Australia's previous high level of activity in this area has been resumed under the current government. It is sensitive to the fact that the expected substantial expansion of peaceful nuclear energy in the region will need increased regional cooperation to avoid proliferation risks and ensure that safety and environmental concerns do not increase. For this, a reinvigorated NPT and IAEA are necessary.

As Michael Clarke notes, the logic of restraint that prevailed during the Cold War and underpinned the support for the NPT, and which saw the need for nuclear weapons as having diminished, was undermined by the gradual US revitalised attitude to nuclear weapons in the post-Cold War period, especially as questions of 'rogue states' and terrorism arose (Clark 2008: 317–319).

In the USA, nuclear weapons remained central as a counter-proliferation tool. Together with its other actions, this led to a view after September 11 that the USA was a country to be deterred rather than a country practising deterrence to discourage aggression by others (Nuclear Age 2003; US Institute for Peace 2009). The Anti-Ballistic Missile Treaty was revoked, the CTBT fell off the agenda, the Proliferation Security Initiative (PSI) was unilaterally established rather than through the UN and there was a lack of support for a Fissile Material Cut-Off Treaty (FMCT) to limit the production of fissile material.

These factors have affected the non-proliferation regime to the point where the US Institute for Peace says 'we may be close to a tipping point on nuclear proliferation' (US Institute for Peace 2009). The logic of restraint is now much more in question and the problems facing the NPT and their adherence to the NPT of NNWS have increased considerably. As Marianne Hanson has argued, a paradigm shift in policy in the NWS, and particularly in the USA, is needed (Hanson 2005: 313).

The Obama Administration indicated a need to ensure the 2010 NPT review would not fail. It expressed its wish to renew arms control with Russia through negotiating a successor to the Strategic Arms Reduction Treaty. President Obama also indicated that Russian help on Iran's nuclear weapon programme would reduce the need for a missile defence system (Crail 2009). Although his Secretary of Defense said that he saw further testing as necessary, President Obama called for the US Senate to reconsider its opposition to ratification of the CTBT. Given the recent agreement in the Conference on Disarmament to negotiate an FMCT, which has been welcomed by Australia (Smith 2009), it would be a significant step if the USA were to pursue an effective FMCT.

The Australian government is committed to supporting the NPT process and to reducing the acknowledged weaknesses of the treaty at the 2010 review. The debate in Australia mostly reflects views supporting this approach but there are alternative views suggesting that the flaws in the NPT regime are sufficiently damaging to its legitimacy and effectiveness, that there is a need to move away from the NPT and to seek alternative ways to deal with nuclear proliferation (O'Neil 2005; Wesley 2005).

The domestic debate is continuing but there are no signs that the Australian government accepts the case for departing from its continuing support for the NPT. It was hoping that some of the negative effects on the NPT of the Bush Administration – that led to an acrimonious outcome at the 2005 NPT review and the growing decline of the legitimacy of the NPT – would be ameliorated during the Obama Administration.

Australia's attitudes towards the nuclear fuel cycle

Australia shares the wider concerns that the greater the number of states that move towards a complete nuclear fuel cycle, the greater the possibility of horizontal proliferation of nuclear weapons. Australia's existing policy is consistent with a view that there is adequate enrichment capacity in the world, existing or being developed, and that Australian uranium should be enriched in existing facilities and then exported to states that are parties to the NPT and adhere to the Additional Protocol.

Moreover, developing a nuclear fuel cycle with existing enrichment technology is economically costly for, and is beyond the capacity of, many smaller developing countries or those with limited resources. On the other hand, for countries developing civilian nuclear power plants, security of supply of enriched uranium is a critical consideration. So too is the question of reprocessing, disposal and storage of spent fuel.

To limit the incentives for states to seek fuel supply security with enrichment capabilities, calls have been made over several decades for the development of multilateral enrichment facilities or fuel banks, preferably under international supervision.

In 2007, under the Coalition government, Australia became a member of the Global Nuclear Energy Partnership (GNEP), organised and led by the USA. GNEP consists of some 30 countries, including China, Japan and South Korea from Asia. The stated aim of GNEP is to promote nuclear energy while preventing nuclear proliferation. As well as cooperating in the transfer of technology, its original aim was to provide enriched uranium in a form of 'lease and take back' basis, with a fuel services programme as a package consisting of fuel supply and spent fuel treatment services. In return for their forgoing enrichment and reprocessing activities, it would provide nuclear fuel services to developing countries to start a nuclear power programme. Limiting nuclear fuel production to a few countries that have already had capacity to do so would help reduce proliferation concerns. Part of the original aim of GNEP was to encourage the establishment of advanced reactors that would reprocess and reuse spent fuels and so reduce the size of nuclear wastes, although this has since been dropped as part of the GNEP programme (Horner 2009).

The initial judgement of the Australian Safeguards and Non-Proliferation Office (ANSO) was that, rather than taking back wastes, Australia would be a user of the GNEP services and send any wastes produced in Australia to a country with advanced fuel cycle technologies to recycle them (ASNO 2007). When Australia joined GNEP, however, it reserved its right to enrich uranium but also said it would not take back the world's nuclear wastes. The issue is still on the agenda of the IAEA where member states have put forward several proposals in a similar nature to GNEP regarding nuclear fuel services. Although having attended the last GNEP meeting, Australia has so far maintained its position that it would not take back the world's spent nuclear fuel.

Lease and take back arrangements for nuclear fuel are not new. It was a practice followed by the Soviet Union and one that is now offered by Russia in respect of its nuclear power plant exports, including the one it is building in Iran. A number of proposals for multilateral nuclear fuel supplies have been put forward and all pledge to place the nuclear fuel production and supplies under the umbrella of the IAEA. By 2007, some 12 proposals had been catalogued (Rauf and Vovchok 2008). None of the proposals appears to include take back provisions.

A problem with the various proposals for limiting enrichment activities largely to NWS and their allies (which would include Australia and Canada were they to take the enrichment track) is that it would perpetuate the existing resentment of the two-tiered system established under the NPT that many NNWS see, or claim to see, as discriminatory. From that perspective, GNEP in particular could be seen less as an internationalist programme than one protecting the enrichment monopoly of the NWS. Meanwhile, many developing countries wishing to develop a nuclear energy programme are happy with the arrangement because building nuclear fuel capacity and facilities is not only economically expensive but technically difficult. Given most developing countries would not have a large nuclear power capacity anyway, it would serve their interest to purchase the fuel from multilateral suppliers.

Another problem is that Australia's policy of limiting the countries to which its uranium could be sold or transferred to third parties would be difficult to sustain under the terms of GNEP (Belac 2009: 6). The ability of a country, or group of countries, to block exports of nuclear material for reasons unconnected with the trade itself puts that security at risk; Australia's deferring of its commitment to exporting uranium to Russia because of Russia's conflict with Georgia in 2009 is a case in point.

There has been considerable criticism of the GNEP by arms control groups (Union of Concerned Scientists 2007), environment groups and the National Academy of Sciences (2006) in the USA. In Australia, criticism was made on a variety of grounds. The arms control groups argue that GNEP would encourage rather than discourage proliferation; the environment groups see GNEP as necessarily involving nuclear waste returning to the uranium suppliers, such as Australia where a nuclear waste depository would create all sorts of long- and short-term environmental problems. Given that the reprocessing programme was dropped from GNEP, the issue is how the international community could ensure safe and secure management of considerable fissile material in individual countries.

Australia's participation in GNEP came about because of a series of influences. Nuclear enrichment and reprocessing in Australia had been off the agenda since the 1970s and re-emerged only when the global climate change and energy shortages issues arose after 2003. They showed up when the global price for uranium reversed its downward trend after 2002 as secondary supplies disappeared while prospects for nuclear power expansion looked bright. Prime Minister John Howard wanted to expand uranium sales as a way to counter the criticism of the Coalition government's inaction on climate change. He also saw possibilities for greater economic benefits from an enrichment industry in Australia by selling a value-added product rather than simply the basic raw material (Howard 2006). In 2006, he raised the issue of nuclear power in Australia, calling for a full-scale debate on the issue. This led to the establishment of a taskforce under a supporter of civilian nuclear power for Australia, Dr Ziggy Switkowski.

The taskforce report supported the expansion of uranium mining and export. It saw nuclear energy as a practical alternative of Australia's predominantly thermal electricity production. Nuclear power would be economically competitive with coal-fired generation capacity provided carbon tax would be included in the costs of competing fuels. The report concluded that there was an opportunity for Australia to be a participant in the wider nuclear fuel cycle (Australian Government 2006). It noted that an Australian development of a laser enrichment process, the Silex process, now being commercially tested by an American company, would lower enrichment costs. It was developed at the Lucas Heights nuclear establishment over about 20 years and sold to a private company, Silex Systems Ltd, in 1994.

The problem with lower enrichment costs, if they materialise, is that reducing the cost barriers to an enrichment process would make it easier for countries interested in setting up clandestine programmes for weapons production to acquire enrichment capabilities, and hence increases the possibilities of proliferation. The taskforce chair subsequently said that the priority should be for Australia to build nuclear power plants rather than uranium enrichment facilities.

Were nuclear power plants to be built in Australia, more pressure would exist to establish a uranium enrichment plant in Australia, even though the economics could well militate against it. Thus, only if it became a supplier, rather than a user, of the nuclear services provided by GNEP or a supplier in a multilateral fuel bank would it be likely to be economic. That, as observed earlier, would pose problems for Australia's selective export policy.

The present ALP government has said that it does not support moving to uranium enrichment or support the development of nuclear power. The Coalition by and large maintains its position in favour of the idea of nuclear energy development in Australia. Caution was raised when some people argued that Australia, with its nuclear expertise (even if this is now much less prevalent), should build a uranium enrichment plant. The debate on the issue in Australia has been followed closely by countries in the region (Davies 2006: 15).

The Australian debate

We need to separate the interests and opinions behind uranium export in the form of uranium oxide (yellowcake), and those behind the export of low-enriched uranium (LEU) used for nuclear power generation. No propositions have come forward for the production of highly enriched uranium (HEU). The main debates on uranium mining and exports of uranium are between the miners and the environmental groups. Aboriginal groups do not have a uniform position on mining. Their viewpoint often depends upon how the location of mining and the linked environmental impacts might affect their spiritual sites and their settlements although in such cases they have, at times, been strong opponents of uranium mining. For example, in the 1990s a bitter public dispute erupted in the Northern Territory. The Ranger Mine owners had decided, with the support of the territory government, to mine uranium at Jabiluka in the Kakadu National Park, a world heritage site and one that is important to Aboriginal people. The body representing Indigenous people accepted the mine, if reluctantly, but in 1996 a group of traditional owners opposed it and eventually won their right in 2005 to block the mine (Aboriginal People 2005).

Miners and investors in the mining industry are clearly supporters of the development of uranium exports and this extends beyond simply uranium miners since uranium is often found in association with other minerals, notably copper and gold. Clearly the companies already producing yellowcake have been keen to see their expansion programmes approved as, subject to meeting environmental requirements, the Rudd government and several state governments already did. Exploration has led to further discoveries and the companies involved will seek approvals to develop and export. New mines have recently been approved in Western Australia and South Australia but they are not yet in production.

Environmental groups are mostly strongly opposed to mining and exports of uranium. At the margins of the environmental movement, there is debate about the relative risks of nuclear power and of climate change and global warming. This is best illustrated by the changed view of Tim Flannery, a noted scientist, environmentalist and author, who seems to have softened his view on nuclear energy. He believes the dangers of climate change are such that nuclear energy should be accepted provided sufficient care is taken to minimise its harmful effects. He has also criticised Australia's unwillingness to sell uranium to India (ABC News 2009). This more benign attitude towards nuclear energy has not yet been reflected in the basic policies of the main environmental groups. For example, the World Wildlife Fund appears to have moved away from active campaigning against uranium mining, acknowledging that, although uranium mining will inevitably take place, nuclear energy will not solve the climate change problem. Friends of the Earth, the Australian Conservation Foundation, Greenpeace and other similar groups can be expected to continue to campaign against uranium mining and more strongly still against any expansion of the nuclear cycle in Australia.

A slight majority of Australians seem to have accepted mining and exporting uranium. One opinion poll in 2006 showed a small majority in favour, but down from the support levels in the 1980s and 1990s. A slightly larger majority supports the export of uranium to China, seemingly reflecting climate change concerns about China's coal-fired power generation (Roy Morgan 2006).

Several opinion polls have indicated that when the nuclear power topic is raised, siting becomes a critical issue. When, in 2006, the idea of developing nuclear power in Australia re-emerged at the instigation of the then Prime Minister John Howard, a counter-tactic by the independent think tank, the Australia Institute, listed a range of sites in Australia that could be deemed suitable for nuclear power plants. Because the potential sites would need water, be close to the large load-centres and have easy access to a substantial electricity network, the Australia Institute speculated, the nuclear power plants would most likely be built in coastal areas, which in Australia are the more favoured residential areas (Macintosh 2007a). Although public opinion polls suggest the population is not greatly divided over the merits of nuclear power, even those who favour it tend to be against having nuclear power plants in their own areas.

Since the issue was raised for public consideration in 2006, various polls over the period show that support for nuclear power has not changed significantly – usually about 40 per cent in favour and a slightly larger number opposing, with a sizeable undecided group (Is Opinion 2009). Support for the introduction of nuclear power in the respondent's neighbourhood, however, was much lower with about two-thirds opposing and a quarter supporting local siting of a nuclear plant (Macintosh 2007b).

The issue of developing nuclear power plants in Australia raised considerable media interest in 2006 when John Howards openly talked about the possibility. A small scientific group in support of a nuclear power programme was counter-balanced by the scientists behind the environmental opposition to nuclear energy. Major mining or energy companies, however, have not indicated, at least in recent decades, their desire to get into the nuclear energy industry, beyond the mining and export of uranium oxide. Rio Tinto was an exception and it called on then Prime Minister Rudd to rethink his ban on nuclear energy, as did the Australian Workers' Union (Ackerman and Franklin 2009). Some companies interested in nuclear technology would see a benefit from an expansion of the industry, but so far they do not include any of the 'big players'.

As discussed in the introduction, interests in a nuclear industry among the Australian defence were clear in the early post-WWII years when the move to a nuclear power industry was seen as a way towards the development of nuclear weapons. Such interest has vanished since the establishment of the US alliance and the nuclear umbrella it is assumed to provide to Australia.

Whatever the federal attitude to nuclear power, the siting issue is also a matter for state and local government politics. When some local businessmen established a company to investigate the possibility of building nuclear power plants in South Australia and Victoria, the two states indicated that they had legislation in place to prevent this, as do some local governments. The federal government of the day then threatened overriding legislation to make such decisions possible.

Australia in the international and regional uranium market

Australia is clearly able and willing to contribute substantially to meeting global and regional uranium demand as this demand grows with the expansion of nuclear energy programmes worldwide. The International Energy Agency (IEA) projections suggest that while, globally, nuclear power generation in the next decade or two will not progress as fast as global electricity demand, it will still grow significantly (IEA 2008: 147, 456); Asia would be a major area of increased demand for some time, notably in China and India but also with some expansion in South Korea and Japan. In 2008, according to the World Nuclear Association (WNA), over and above China's 11 nuclear power reactors in commercial operation, 12 more were under construction as of 2009 and at least 12 more were about to start construction. China has fast-tracked the approval and construction of some of the new plants (Xin 2009).

China has its own deposits of uranium but according to the WNA, they are low grade and inefficiently mined. Reliance on uranium imports will, therefore, remain an important issue. Other planned expansions in the Asian region, not including India, are limited and likely to be slow.

The Indian plans for additional nuclear power reactors are substantial, with 6 reactors under construction and up to 25 planned and proposed as of 2010. Historically, Indian nuclear plans have been slow to materialise; among other things, fuel shortages have at times delayed commercial operations. The decision of the Nuclear Suppliers Group, which included Australia, which agreed to an exemption for India provided safeguard arrangements were made with the IAEA, removed some of the previous constraints on the transfer of nuclear materials and technology to India. Nevertheless, Australia has declined to sell uranium to India as it is not an NPT country; that policy is unlikely to change soon although counter-arguments in Australia are likely to grow (Medcalf 2008: 11; McDonald 2009). To a large degree, however, the uranium oxide market is a global one and India's added demand will add to global demand.

Domestic and overseas investment in Australian uranium companies has increased given the expectations of growing uranium demand. Overseas investors include Indian and Canadian companies seeking interests in Australian uranium development. Japan already has interests in Australian uranium and China too has looked to invest in Australian uranium companies; Sinosteel has joined with an Australian company PepinNini in a joint venture to develop a uranium deposit in South Australia and other Chinese companies seem likely to follow. Another Chinese company, China Guangdong Nuclear Power, is seeking effective control of a Northern Territory uranium developer, Energy Metals.

Australia and regional and international scientific and technical cooperation frameworks

Consistent with its obligations under the NPT, Australia has a long history of involvement and cooperation in nuclear matters with Asian countries, notably through the Australian Nuclear Science and Technology Organisation. This cooperation covers a range of nuclear issues, including nuclear health and safety, security, research, environment and education. It also participates actively in such forums as the Forum for Nuclear Cooperation in Asia, the Asian Senior-Level Talks on Non-Proliferation and the IAEA's Regional Co-Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology. Australia has a 'strong record' in contributing financially to the IAEA's Technical Cooperation Fund and in supporting cooperative IAEA research projects (ANSO 2009).

Australia was a party to the 1987 RCA. It ratified each of the three subsequent extensions, with ratification of the fourth extension expected shortly. In 2007–08, Australia provided training in the areas of nuclear safeguards, nuclear security and export controls to more than 180 professionals from 15 regional countries.

Since 2007, in collaboration with Indonesia and South Korea, and in the Asia-Pacific Economic Cooperation (APEC) context, Australia has been active, through ASNO, in seeking to develop an Asia-Pacific association on regional safeguards. The third informal meeting in Seoul in 2009 agreed to establish an Asia Pacific Safeguards Network (APSN). Its aim includes regional operational capacity building in relation to NPT obligations and related conventions. Training programmes are also an important element of such networks.

There has also been effective cooperation between the Australian Radiation Protection and the Nuclear Safety Agency and the related agencies of governments in the region.

In sum, Australia participates actively in what Andrew Simon concluded are 'good multilateral and bilateral frameworks for addressing many of the scientific, technical and management concerns associated with nuclear development' (Simon 2008: 17); these include capacity building, training and management, and safeguards design and implementation.

Nuclear waste storage in Australia

Australia currently stores its limited nuclear waste at the site of its nuclear reactor at Lucas Heights. Some of this would have been processed overseas to convert it into stable waste for long-term storage.

Were Australia to develop a nuclear enrichment capacity as part of a fuel supply mechanism, there would be a security case for taking back the spent fuel for secure storage in Australia. A process for treatment of highly radioactive waste for disposal underground, SYNROC – developed in Australia and currently being evaluated in the USA – would be a possible medium should government policies change (Ng 2009). Political and environmental sensitivity makes this highly unlikely however.

While various geologically acceptable sites for safe depositories of Australia's own nuclear wastes have been identified, efforts since 1978 to gain public acceptance for these sites have not been successful. The Howard government legislated for a site in the Northern Territory that remains within the federal jurisdiction, and one had been proposed by representatives of the traditional (Aboriginal) owners. A recent Senate Committee report under the Rudd government said that the existing legislation dealing with nuclear wastes was deeply flawed and should be repealed. It looked for a new policy framework involving a more consultative approach, although this did not specify any particular solution (Senate Standing Committee 2008). In the event, despite it now being opposed by a larger group of traditional owners, the Labor government decided not to repeal the legislation (ANF n.d.).

Arguments that Australia should be responsible for wastes that come from the uranium it exports are raised from time to time but these are seldom supported. This was also the case with an earlier argument that Australia should take back the ash from the coal it exports. One notable exception was ex-Prime Minister Hawke. Arguing it as an act of environmental responsibility, he said that Australia had the geologically safest places in the world for the storage of wastes and that Australia should promote itself as a safe place for the world's nuclear wastes and the money raised could go towards domestic environment problems and to support the Aborigines (Hawke 2005). Some scientists are cautiously supporting the view that the issue is mainly one of public perception rather than a question of safety or risk. This was also the position of the Switkowsky review (Australian Government 2006).

We noted earlier the refusal of the Howard government to accept importing the world's nuclear wastes within the GNEP programme. The Rudd government similarly rejected the proposal of accepting the world's nuclear wastes. This leaves the handling of spent fuel to international action – which seems unlikely to provide a solution – or, as Richard Garwin suggests, storing the wastes safely next to the nuclear reactors as is generally the case at present (Garwin 2009).

Conclusion

Given the prospective growth in nuclear power in the Asian region, the short-term implications for Australia are that it is well placed to expand uranium exports and, despite competitors, to gain an increased share of the world and regional market.

The longer-term implications, however, arise because of Australia's potentially conflicting objectives with the added use and production of fissile material in the region. Against the economic and climate change benefits of the growth in nuclear power and in its uranium trade are the risks to its nuclear non-proliferation objectives. The IAEA and the NPT have provided the framework for Australia under which it avoided this dilemma in the past through the safeguards regime and its bilateral safeguards agreements. For this framework to remain effective, it requires a shoring up and reinvigoration of the NPT and some strengthening of the safeguards monitoring and verification processes, particularly as they apply in the region. This is so even if, as seems likely, Australia remains simply an exporter of yellowcake.

It will be in Australia's interests, therefore, to encourage and support regionally the implementation of procedures for safe and secure handling of nuclear materials. The existing institutional arrangements provide useful mechanisms for these purposes but greater effort may be needed.

The question of the complete nuclear fuel cycle has challenging implications for Australia. It is unlikely that Australia will develop its own enrichment capability while the political mood of politicians and the public remains at the present level. Admittedly, both political parties have changed their views substantially over time, but over a long time. Progress on resolving the problem of multilateralising enrichment capabilities to minimise proliferation risks will be slow and events could well take over. Clearly, for Australia, GNEP may not be the best path to follow. The question of safe storage of spent fuels, perhaps more important in the region than weapons development, is likely to depend for some time on the management and skills in the countries utilising nuclear power. Australia already has effective frameworks for cooperation and exchanges in the region that may need developing further to assist in enhancing the skills needed.

The NPT framework is seen as fundamental to Australia's non-proliferation approach; the implications of a failure coming out of the 2010 review would be especially serious. The action it has taken with respect to the International Commission will be a valuable starting point for Australia at the 2010 NPT review but essential to a better outcome than at the last review is a significant shift in US policy. The first steps appear favourable, but Australia should do what it can to reinforce those first steps. Some degree of regional consensus, if possible, or at least some common ground on nuclear security issues in the region, whether in the APEC, the ASEAN Regional Forum (ARF) or the East Asian Summit context, would make a significant contribution.

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Note

1. For example, both China and Japan have sought to include energy security in the bilateral trade treaties currently under negotiation.

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11
Nuclear Energy and Development

Xu Yi-chong

There is a general consensus that the current pattern of energy production and consumption is not sustainable, regarding both energy supplies and the environment. There is an agreement that low-carbon energy technologies need to be adopted as soon as possible to avoid putting the world onto a potentially catastrophic trajectory. Energy is at the centre of the discussion of climate change because it contributes to over 80 per cent of global greenhouse gas (GHG) emissions. Given the long life-span of energy facilities, what technologies are adopted today will affect the climate future in the next 40–60 years. A wide range of suggestions has been proposed by governments, international organisations and non-governmental organisations, by experts, government officials and laymen. There is, however, no agreement on what actions each country should take or how the international community could take necessary actions to solve energy problems.

The challenge for each individual country is 'to balance four competing objectives – sustain economic growth, increase energy access for the world's poor, enhance energy security, and improve the environment – tall orders' (World Bank 2010b: 191). The challenge for the international community is how to address 'the inequity in the global distribution of past and current emissions and in current and future damages' (World Bank 2010b: 38). For Asian countries, especially developing ones, the stakes are high, not only because the poor tend to be more vulnerable to climate change threats but also because their development depends on an adequate supply of modern energy. Buoyant economic growth in the past three decades in Asia has fuelled insatiable thirst for energy and rising energy demands are driven by industrialisation, urbanisation and prosperity, all of which are part of a broader process of development that has lifted millions out of absolute poverty. This process will continue until the mid-twenty-first century. These countries nonetheless cannot provide their citizens with an adequate and reliable supply of modern energy in the way developed countries did in the process of their industrialisation in the nineteenth and first half of the twentieth century. Neither can they stop the process of industrialisation and urbanisation. Economic growth, poverty eradication and climate protection have to be considered in a holistic and integrated manner.

To achieve these competing objectives, countries in Asia, from developed Japan and South Korea to the developing China, India and others, have all adopted some measures on energy conservation: China promised 20 per cent reduction in energy intensity from 2005 to 2010 and to invest $88 billion in ultra-high voltage transmission-smart grid projects by 2020; India planned 10 GW of energy savings by 2012 and Japan and South Korea both pursue a smart-grid system. Improving energy efficiency is the most important effective emission reduction option; yet it is the most difficult objective to achieve because it requires changes in the economic structure (i.e. closing down energy-intensive industries or switching heavy industries to services) and fundamental reforms of institutions (i.e. pricing and regulation).

In addition to energy efficiency measures, countries have decided to expand low-carbon energy technologies: China planned to expand the share of renewable energy to 15 per cent of its primary energy supply by 2020 and India promised to build a total 20 GW renewable capacity by 2012. There are major programmes and mandates in solar, wind, nuclear and hydro, and there is much work being done on bio-fuels in many Asian countries. Investment has gone into the development of renewable energies as well as nuclear energy. For these countries, therefore, it is not a question of either nuclear or renewable energy development; rather they need all the options to achieve the objectives of development, poverty reduction, energy security and environmental protection.

Nuclear in Asia

Nuclear energy has fallen on hard times in many developed countries since the Chernobyl disaster in 1986. Some countries nonetheless maintained their enthusiasm for nuclear power. It provides three-quarters of French electricity and the majority of nuclear power plants in South Korea were built and went into operation in the post-Chernobyl era. Since the early 2000s, geopolitics, technology, economics and the environment have all been changing in nuclear power's favour. Even in countries where nuclear power was banned in referenda, as in Italy in 1987, the combination of the low diversification and heavy reliance on imported fuels, the global volatile energy prices, concerns over energy security and impending climate change policies has modified public perception about nuclear energy (IAEA 2009). In Britain and Sweden, policies were adopted to replace some old nuclear power plants in the coming years. In 2007 alone, the US Nuclear Regulatory Commission received 12 applications to build new nuclear power reactors at seven different sites.

Nowhere is the enthusiasm for nuclear energy greater than in Asia which hosted 35 of the 54 reactors under construction in the world as of the end of

August 2009. In all five places covered in this study, new nuclear power plants are under construction. Those countries in Southeast Asia that do not have nuclear power plants yet, such as Indonesia, Malaysia and Vietnam, have made policy decisions to develop nuclear energy as an alternative source of energy. This enthusiasm is in great contrast to the strong scepticism in continental European countries for several reasons. First, there is a very different perception of nuclear energy in Asia compared to Europe where people still remember vividly the disaster at Chernobyl, as some Germans explained, 'we were only little kids then and had to stay indoors and were not allowed to play in sand-boxes outside in case of contamination.' In Asia, despite the bombing in Hiroshima and Nagasaki, nuclear power is more associated with electricity rather than disasters, and represents technological progress rather than a destructive force.

Second, most European countries have diverse domestic energy reserves, from coal, to oil and natural gas and hydro and they have also relatively easy access to natural gas from other countries. In some of them, nuclear energy has already amounted to a large share of their total electricity production. Their public may have demanded the phasing out of nuclear capacity (as in Germany and Sweden); their governments do not see a way to replace it yet. One major country that does not have a nuclear energy capacity is Italy which depends more on imported oil and natural gas for its electricity (60 per cent) than the European average (25 per cent). This is the reason the country has made a policy decision to embark on a nuclear energy programme, 'with a stated long term goal of 25% in the electricity generation mix' (IAEA 2009: 54). Energy security is a major concern for many Asian countries. Energy dependence on imports in both South Korea and Taiwan is over 99 per cent and in Japan it is over 85 per cent. Even China, India and Indonesia have increased their energy imports in the last decade or so. A sense of energy vulnerability is much stronger in Asia than in Europe.

Third, energy demand in OECD European countries has long been stabilised: the primary energy demand increased by 16 per cent between 1980 and 2000 and 5.2 per cent between 2000 and 2007, with its annual growth rate between 1 and 2 per cent. It will grow by 3.7 per cent by 2030. In Asia, energy and electricity demands in all countries (except Japan) are rising fast and will continue to do so in the next couple of decades. The primary energy demand in non-OECD Asian countries doubled between 1980 and 2000 and then increased by 55 per cent between 2000 and 2007, with 78 per cent in China, 44 per cent in the Association of Southeast Asian Nations (ASEAN) countries and 30 per cent in India. It will double in Asia by 2030 (IEA 2009: 76). The contrast is even starker in electricity consumption: it grew 13 per cent in Europe between 2000 and 2007 while it doubled in Asia where there are still about one billion people without adequate access to electricity. Development levels matter when energy is concerned. Today's urbanisation rate, for example, in China and Southeast Asia (about 46 per cent) is below the level of Europe in 1950. The current urbanisation rate in South Asia is approximately 35 per cent. Energy demands for people in urban areas at least triple that for rural population. Furthermore, despite rapid economic growth, per capita income in Asia remains much lower than the average of OECD countries. GDP per capita in China doubled between 2004 and 2008, but it was only 7 per cent of that in the USA in 2008. In India GDP per capita increased more than 50 per cent in the same period, but it remained only 2 per cent of that in the USA. This means that these developing countries need economic growth and their development needs to be fuelled by modern energy. This demand for modern energy has to be met now, not in 30 or 40 years. Nuclear energy offers a mature low-carbon technology.

Finally, in no European country does coal contribute more than 50 per cent of their electricity, with Germany having the highest share, with 48.75 per cent of its electricity generated by coal-fired power stations. In most Asian countries, except Japan and South Korea, coal-fired generation plants provide more than half of their electricity. Coal-fired power stations produced 81 per cent of the electricity in China and 68 per cent in India. Heavy reliance on coal is creating two immediate challenges: rapid depletion of coal reserves and serious environmental pollution and GHG emissions. These countries have paid a heavy environmental price for their remarkable economic growth. 'Local air pollutants emissions, especially particulates (PM_{10}), sulphur dioxide (SO_2), and nitrogen oxide (NO_x) increased rapidly from coal combustion' (World Bank 2010a: 30). CO_2 emissions in East Asia tripled over the past 20 years with China's CO_2 emissions nearly doubling over the past six years. Similar development can be seen in South Asia: 'On average, emissions have risen by about 3.3 per cent annually in the South Asian region since 1990, more than in any other region except the Middle East and North Africa' (World Bank 2009: 155). Even though these countries, especially China and India, have lower CO_2 emissions per capita, their large population makes the scale of their GHG emissions a threat to the whole planet. Without development and deployment of low-carbon technologies and technology to reduce coal's carbon footprint, the future looks grim for these developing countries. They are among the most vulnerable in the world to climate change threats not only because many are located in low-land regions but also because of their relatively low living standard.

These major differences are behind the arguments for or against nuclear energy development in Asia and in Europe. A large number of developing countries have recently expressed their interest in building nuclear power plants, driven by concerns over energy security, surging fossil fuel prices and rising CO_2 emissions. 'Few governments, however, have taken concrete steps to promote the construction of new reactors' other than in China, India, Japan and South Korea (IEA 2009: 100). These countries, together with Taiwan, have had active nuclear power construction programmes in place for a long time and it is widely accepted in these countries that 'nuclear technology is the only large-scale, base-load, electricity-generation technology with a near-zero carbon footprint, apart from hydropower (potential for which is often limited)' (IEA 2009: 160).

Their position on nuclear energy development also has the endorsement of international organisations, such as the International Atomic Energy Agency (IAEA), the International Energy Agency (IEA) and the World Bank, whose recent study argues that to achieve sustainable energy development, countries in East Asia would have to increase their share of low-carbon electricity generation capacity to about 50 per cent. This three-fold increase in the share of low-carbon technologies would come primarily from hydropower, wind, biomass and nuclear in China; hydro, biomass and geothermal in Indonesia, geothermal and hydro from the Philippines; imported hydro and biomass in Thailand; and hydro in Vietnam (NEA 2008; IAEA 2009; IEA 2009; World Bank 2010a).

Nuclear energy is only one of the energy sources Asian countries have decided to expand in order to deal with the challenges they are facing – rising energy demands, energy security vulnerability and climate change threats. In the region, the relatively high cost of alternative electricity sources benefits nuclear power's competitiveness and concerns about energy security overwhelm those about potential risks of nuclear energy, as the Ministry of Economy, Trade and Industry (METI) in Japan recently explained:

> Nuclear power is a quasi-domestic energy source superior in supply stability and economics .... Without promoting nuclear power, it will be virtually impossible to ensure stable supply or to address global environmental issue.
>
> (quoted in IAEA 2009: 57)

The concerns of meeting the rising demand, energy security and climate change threats can explain the enthusiasm in nuclear energy development in Asia. They can also explain the absence of any widespread anti-nuclear movement in the region. Localised protests against specific nuclear sites do occur and often are effective, but there are no strong general anti-nuclear movements. For both the government and the public, an anti-nuclear movement is a Western luxury and they cannot be too choosy if they need to develop all options (among which nuclear is only one energy source) to meet the demand while mitigating the impact of climate change that already imposes a heavy burden on development.

Nuclear energy development in these countries does not preclude the development of other energy sources, fossil as well as renewable, nor does it occur without facing serious challenges. While both China and India have repeated that coal is the backbone of their energy sector and as their demand for electricity grows they will have to look for other options to diversify sources for electricity generation and to mitigate GHG emissions. According to the Indian Planning Commission, if the country wants to maintain an 8 per cent annual economic growth rate, it would have to triple its electricity generation capacity. If it maintains the current pattern of power generation with coal supplying over 60 per cent of its electricity, India's emissions would approach those of the USA today by 2030. To address this unsustainable energy development, at the end of 2008, India had already expanded its wind power capacity to 9.6 GW. It also plans to expand its hydro and gas potential and nuclear capacity from the current 2 per cent to 6 per cent of total electricity production (World Bank 2009: 157).

China has promised to increase the share of its renewable energy to about 15 per cent and the share of its nuclear energy to about 4 per cent from the current 1.9 per cent by 2020. Non-hydro renewable sources have recently been given priority in terms of funding. Because of the global financial crisis, the Chinese put a huge economic stimulus package together (US$586 billion). Within it, $201 billion was dedicated to green projects, compared to $94 billion in the USA. Financial incentives have led to a rapid expansion of wind generation capacity, from 1.2 GW in 2005 to 12.2 GW in 2008 and 22 GW in 2009. A variety of 'green energy' projects have been launched: China is the world's largest consumer of solar power, yet solar photovoltaic (PV) technology remains problematic for large-scale electricity generation in the world. Research on new tidal and wave technology started in the early 2000s and by 2009, several tidal wave stations were in operation in Zhejiang, Fujian and Guangdong. Most had a capacity of 0.3–0.5 MW and even the most recent one built by the Israeli SDE had a capacity of only 1 MW. In early 2010, a Shanghai research institute with government financial support completed an offshore wind project with 34 units of 3 MW each. The total investment was 2.365 billion yuan (near US$350 million) and a total capacity of 102 MW. The National Energy Administration in 2010 was calling on 11 institutions in several coastal provinces to bid in for more offshore wind power projects in order to decide a base price for the offshore wind power. In sum, China has been developing all renewable energy sources and much more investment went into renewable than fossil energy projects. In 2010, China was expected to add 85 GW generation capacity, among which 15 GW was hydro, 55 GW coal-fired, 13 GW wind, 1.8 GW nuclear and 0.2 GW solar. According to the Chinese officials, to reach the target of 15 per cent of renewable energy and more importantly to deal with the imminent threats of energy security and climate change, China must put in place as many renewable energy projects before 2015.

Other Asian countries are developing varieties of renewable energy too. In South Korea, after five years of construction and US$10 million investment, its first tidal wave station with 1 MW capacity went into operation in 2009. The Philippines has the largest geothermal capacity in Asia. Indonesia has hydro, geothermal and wind power too. There are many more renewable projects in Asian countries; these are new, often innovative projects, yet for now they all have very limited capacity to make a large difference in the immediate future. The costs must be brought down to make them affordable for large commercial operation.

The potential for expanding renewable energy depends largely on the resource availability. Hydro power and geothermal power are limited by the availability of suitable sites. Neither South Korea nor Taiwan has much hydro potential. China has a large hydro potential and hydro is clean and can be used as a base-load to meet demands of industries and a concentrated population but it has many associated social and environmental consequences. Indeed, the hydro projects assisted by the World Bank and Asian Development Bank were so heavily condemned in the 1990s that the Bank cancelled almost all of its lending on hydro projects. The problems involved in developing hydro power stations – resettlement, deforestation, soil erosion and so on – are the very reason for the Chinese government switching to nuclear.

'Biomass is constrained by competition from the land and water for food and forests' (World Bank 2010a: 71). The low availability rate of wind power needs backup generation capacity, normally nuclear or gas-fired generation capacity, which can be turned on and off relatively easily. Unfortunately, East Asian countries do not have either domestic gas reserves or easy access to natural gas. 'Rising dependency on gas imports in East Asia will increase the risks to the security of supply' (World Bank 2010a: 75). Solar power is the most abundant energy source on Earth, but it is so costly that few developed countries are developing it. The cost for one kilowatt hour of electricity ranges from 15 to 225 cents for solar PV, 7–17 cents for offshore wind, 4–16 cents for onshore wind, 5–28 cents for hydro, 12–16 cents for oil, 3,012 cents for natural gas, 2–11 cents for coal and 4–12 cents for nuclear (IAEA 2009: 22). The wide ranges are due partly to different techno-economic assumptions behind the calculation, but more importantly, due to the local economic, social and energy conditions. For example, for countries heavily dependent on energy import, such as Japan, South Korea and Taiwan in this project, nuclear energy is quite competitive when compared to other energy sources, whether renewable or fossil.

This is the conclusion drawn by the IEA and the World Bank – 'there is no technology that has a clear overall advantage globally or even regionally'. It depends on the local energy endowment. Even in one country, such as China and India, no one technology could be adopted to deal with the twin challenges – energy security and climate change. In China, along the coastal regions, nuclear is the option; in the northwest, wind is being developed to supplement coal consumption, in the southwest, hydro is the main source and in far west, solar has been used for several decades already. This is the reason all five countries under this study are undertaking research and development of a wide range of energy sources. Diversifying energy sources is the key to ensuring energy security and sustainable development. It is also seen as a great opportunity for many to lead the field.

To develop, developing countries need modern energy and according to the IEA, electricity demand is growing most rapidly in non-OECD Asia and will continue for the next two decades before it can stabilise. These Asian countries are expanding their renewable energy capacity, but this will not be sufficient to meet all the rising demands unless new technologies are developed and transferred to these countries. In other words, the new renewables and nuclear capacity will both need to come on line to supplement the development of fossil fuel capacity. 'It is ethically and politically unacceptable to deny the world's poor the opportunity to ascend the income ladder simply because the rich reached the top first' (World Bank 2010b: 44). That is why the transfer of affordable low-carbon energy technologies was one of the major demands made by the developing countries at Copenhagen and was also one of the issues on which developed and developing countries could not reach an agreement. Meanwhile, developing countries cannot afford to wait until new technologies are available; they need electricity now and will use whatever proven technology is available. For the five countries in this study, they have already mastered the nuclear power technology and they are expanding it as a crucial part of their energy mix.

Challenges

The ambition to expand nuclear capacity to a larger share of their total generation capacity, however, cannot easily be translated into reality because of the economic, social and technical constraints. 'Nuclear projects face significant hurdles, including extended construction periods and related risks, long licensing processes and manpower shortages, plus long-standing issues related to waste disposal, proliferation and local opposition' (World Bank 2010: 160). Nuclear power plants have a 'front loaded' cost structure (a feature shared with most renewables); that is, they are relatively expensive to build but relatively inexpensive to operate (compared with fossil-based generating capacities). This raises the challenges of finding sufficient initial investment in new nuclear power projects. Even in countries, such as Japan, South Korea and Taiwan, where there is a mature financial market and capital can be raised, government's involvement is often needed as a guarantor or to provide concessional loans. The huge capital requirements, combined with risks of cost overruns and regulatory uncertainties, often make investors and lenders very cautious, even when demand is robust.

For countries like China and India, the government is in the driver's seat in financing these projects. There is the issue of how the government can balance the competing needs, not only energy needs between supply and demand, among various sources, but also economic and social needs. In these countries at a relatively low development stage, large projects can often trigger inflation pressure that the government must take into consideration in its decision to finance them.

All five countries included in this project have had an active nuclear energy programme and developed a certain degree of technical competence. Yet each faces its distinct technical challenges: for Japan, it is to develop the technology to make nuclear energy sustainable, as discussed by Graham in Chapter 6. In China, there is yet to be one base model of reactor technology to be adopted, standardised and localised, as has been done in South Korea. Without doing so, the nuclear industry in China cannot bring the costs down. The multiple technologies used in China today make the nuclear industry difficult to regulate and to ensure the safety of nuclear power plants. 'Nuclear power can realise its potential for reducing CO_2 emission only if it is safe and economically acceptable' (IAEA 2009: 52). For India, the recent US–Indian bilateral agreement and the waiver by the Nuclear Suppliers Group have allowed others to trade nuclear materials with India (see Chapter 4). Yet, India still wants to fulfil its long-held dream of developing the ability to turn its large deposits of thorium into nuclear fuel.

Nuclear energy may be favoured in many Asian countries. Building nuclear power stations in specific sites, however, has always met opposition. People are concerned about potential risks of power plants, long-term radioactive waste management, spoiling of scenery or forced change of life for those living in the selected site. Nuclear energy projects can be easily used as political footballs by politicians (as in the case of Taiwan) and between different levels of governments (as in China and Japan). Public acceptance is necessary for any nuclear power projects no matter where they are; often governments, even the Chinese, are reluctant to compromise the public support just for a nuclear project.

In sum, energy is indispensable for development. Improving people's living standards without undermining the sustainability of development is the main challenge for large swathes of the world. Without a paradigm shift in the global approach to energy, global GHG emissions will continue to rise. Nuclear energy can contribute to mitigate some of the immediate challenges Asian countries face – rising energy demand, energy insecurity, volatile energy prices and climate change. The economics of nuclear power may be improving and the increasing CO_2 costs of fossil-based electricity generation may make nuclear energy more attractive. 'A nuclear renaissance is possible but cannot occur overnight' (World Bank 2009: 160). The desire to expand their nuclear generation capacity in the five countries under the study is real, but then, so are the challenges.

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