Kaulir Kisor Chatterjee

Macro-Economics of Mineral and Water Resources

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Indian School of Mines
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Dedicated to my inner God
who inspires me to do all that I do

Preface

This book had for long been in my mind. The issues like land acquisition, forest and biodiversity conservation, environment preservation, energy security and water security have been and are being talked about in many countries by the planners and industries alike. In some countries, the more visionaries amongst the planners are beginning to worry about even mineral raw material security for sustaining the industries without affecting agriculture and food security. By now, the industrial products have so much pervaded into the daily lives of one and all that today's humans cannot imagine a single day without them just like food and water.

After publishing my three books on the uses of energy minerals, metals and metallic minerals, and industrial minerals, rocks and freshwater during the last decade, I was somewhat disturbed by the absence of a single ready-reckoner from which one can know about the uses of hundreds of metals, minerals and rocks in countless industrial processes and products and also from which one can quickly know, given the name of a product or process, the metals, minerals and rocks that go into it. Another disappointing situation arises from the fact that I have not yet come across a policy research institution dedicated to and engaged in holistic research covering all intricately interrelated policies concerning land, water, mineral, energy, forest, biodiversity, environment and industry for which the first step is to recognize the complexities of the relationships and the limitations of the options.

However, launching of this book project had somehow been getting delayed. It was only when I was one day sharing my thoughts with Mrs. Varsha Avinash Gharote, my ex-colleague in the Indian Bureau of Mines, that my long-dormant plan got revived and I mustered my will and resolution to draw up a plan of the chapters and their outlines and jotted down the first line of the first chapter. That small step about a couple of years ago has now given birth to this book. I am indeed indebted to her.

Besides my personal field studies and interactions, this writing has required me to rummage through whatever relevant literature that I came across and to surf through the sites of the UN, USA, World Energy Agency, World Coal Institute and many more international government and non-government bodies including those of India and USA. For keeping me up-to-date with news of current developments, the newsletters/journals published by the Federation of Indian Mineral Industry, the Mining Metallurgical Geological Institute of India, and the Mining Engineers' Association of India and various other journals and newspapers were also helpful.

It is hoped that the book will be useful to policy researchers across the world and also the teachers and students of mineral economics, mining engineering and geology. The latter section of readers may find Chaps. 9 and 10 especially useful.

Nagpur, India
October 7, 2014

Kaulir Kisor Chatterjee, Ph.D.

Introduction

Minerals have been both the means and the cause of countless battles and wars fought since time immemorial. But, today, wars are fought not merely with weapons but with economic and industrial strength, which in turn come from the minerals. Mineral resources being natural endowments most erratically distributed over the globe, there is not a single nation or state that is fully self-sufficient in all the minerals needed by its industries and people. In modern times, a country's military strength is ultimately determined by how many minerals and how much resources it possesses. From the first mineral flint used more than 100,000 years ago to fullerene and shirasu towards the fag end of the twentieth century, and still later, in the twenty-first century, longsdaleite, a mineral harder and tougher than diamond; from the first metals copper and gold around 6,500 years ago, to the host of nuclear metals discovered during the twentieth century; and from the energy harnessed from coal for running industries in the early seventeenth century to that harnessed from uranium in the twentieth century—the evolution of economic usage of minerals has kept pace with that of the human civilization. Goods and services are turned out by the industries every day and we see and use them. But the minerals, which are made use of by the industries for producing those goods and services, are not at all seen by us. Every moment of our lives, we are using one or the other mineral without being conscious of it.

Humans need three basic natural entities for not only progressing but also surviving—land, ecology and mineral resources. Humans are born on land, depend on ecology for breathing and living and they are differentiated from their animal predecessors by how they exploit and utilize the mineral resources. While both land and mineral resources are finite, the latter are invisible, underground and unpredictably erratic both in geographic and geologic distribution as well as in their nature. And today these entities are in fierce conflict with each other. This conflict has become fiercer and fiercer since the onset of the industrial revolution about 250 years ago, later on getting a boost in the twentieth century by the two world wars and the Great Depression in between them to manage which John Maynard Keynes promoted the Epicurean ideology. Moreover, for extraction of minerals both land and ecology have to be destroyed.

This conflict has resulted in a significant shrinkage on the mineral resources endowed by nature which can actually be extracted and supplied. On the other hand, increasing population and industrialization are exerting relentless pressure on the mineral supply triggering worldwide a sense of insecurity about how to keep the industries going 20 or 30 or 50 years down the line. This underscores the importance of an approach to management of the mineral resources from a macroeconomic perspective i.e. in a national or regional scale.

Another essential economic commodity is water. While groundwater is regarded as a mineral, surface water is not. But they are links in the same water cycle along with seawater, atmospheric water and wetland water. While the humans, the agriculture and the industries directly consume potable freshwater, all the water subsystems are equally important from the ecologic point of view. Sources of fresh water—both surface and underground—were the cornerstones of the civilizations. Yet hardly any attention is given to management of its resource by the governments across the world.

The book seeks to bring to focus the indispensability of minerals, the vulnerability of the humans and also the issues that the governments across the world have to face and their management. It has been organized into ten chapters.

The first chapter 'Mineral Resources and Land Cover' deals with the paradoxical relationship between the land and the mineral resources. In spite of the classical economists considering the latter as a part of the former, the two are different in the eyes of both nature and the laws of different countries. The evolution of the process of division of land into geographical and political units and that of the 'land ownership' concept have been traced back to the early civilization of the human race. And this happened without affecting the mineral resources which lay hidden underneath the land, in oceans and in space. Moreover, the geological history of minerals is older than that of the land. It has also been highlighted how mining can contribute to both destruction of and value-addition to land. In this chapter the attributes that first determined the value of a land and how this value shifted to the mineral resources lying underneath have been described and a brief history of conquering land solely for acquiring control over mineral resources has been presented, then the present day parameters of the value of land such as forests, industries, buildings, freshwater source, infrastructure, various utilities and archeological significance have been discussed; and finally the laws relating to land have been analyzed objectively.

In the second chapter 'Minerals and Other Economic Entities', the special and unique characteristics of mineral resources vis-a-vis various overground economic entities have been explained. The latter include agricultural produce, forest and wildlife, biodiversity, human settlement, industries, real estate and environment. The essentiality of minerals to the very survival and civilization of man; the finiteness, non-renewability, invisibility and perpetuity of mineral resources; the uncertainty of their quantity and quality; and their location-specificity and independence of any political boundary—all together set mineral resources apart from the other economic entities. Keeping these differences in view, the economic significance of each of these entities as well as their pros and cons has been critically discussed in this chapter. The outlooks in India and other countries towards all these economic entities have also been reviewed. Finally, the land management policy in India along with the deficiency therein has been critically analyzed.

The third chapter 'Relationship between Minerals and Human' traces the history and significance of minerals. All productions are essentially the result of interaction between humans and one or the other mineral which comes through mining. Although a section of the humans take part in the production of minerals, all humans are actually consumers of minerals either directly or indirectly. Consumption of minerals is related to growth of population and industrialization both of which have registered stiff rise after the industrial revolution. The history of exploitation of various forms of energy culminating in coal, petroleum and uranium and now in the renewable energy has been tracked. The relationship between growth of population and that of consumption of the important metallic and non-metallic minerals has been analyzed with the help of statistical data. As regards production of minerals, the limitations and the technological opportunities of exploration in remote locations, ocean and space resulting in augmentation of the knowledge of the reserves and resources have been described and explained with the help of statistical data. The emerging technologies have created new demand for certain not-so-widely used metals like gallium, germanium, rare earth metals etc., and this trend has been demonstrated with the help of statistical data. The need for management of such challenges by policy measures has been stressed.

The fourth, fifth and sixth chapters deal with different issues relating to energy and include sources, security etc. In these three chapters, as many as 29 sources of energy have been grouped into nonrenewable conventional, nonrenewable unconventional, renewable conventional and renewable unconventional. Each of these has been described and analyzed in terms of their advantages and disadvantages, measures for mitigating the disadvantages, status of production and consumption in India and certain other economically important countries, governmental policies and future trends. Finally, the determinant factors for deciding on the optimum energy mix in any country have been critically analyzed—need for diversification of generating capacity, local availability, ease of transportation, infrastructure, human skill level, cost and price, requirement of investment, dynamics of fiscal and other policies of governments, political viability, risks of natural hazards and man-made disruptions, nature of resources, geological factors, substitution, accessibility to foreign source, environmental and ecological regulations, problems of land acquisition and those of mindset. Evolution of energy-mix models in the world, USA and India have been shown with the help of statistical data sourced to Indian and international agencies. Finally the energy security aspects and some significant innovations in the field of energy have been described. In these chapters, statistical data have been quoted profusely and there are as many as 26 tables.

The seventh chapter is about groundwater and water management. Mode of occurrence of ground water has some similarities with that of the minerals, particularly petroleum, and it is legally recognized as a mineral whereas surface and atmospheric waters are not. However, groundwater, surface freshwater, ocean water, atmospheric water and wetland water behave as parts of the whole water resource system and there are constant and smooth interactions amongst all these forms of water. In this chapter the desirability of approaching them as one system has been emphasized. Quality parameters of water have been described as also the economic significance of virtual water, blue water and grey water. Uses and consumption of water for agriculture, industries, drinking, household activities and mineral water production have been described with the help of statistical data as also the economic significance of all the forms of water and the role of environment. Critical appraisal of the management challenges like resource nationalism; quality; distribution amongst the different end-users; various socio-political and economic issues; and ensuring sustainability through science, technology and innovation has been presented. The reasons why many countries have not been able to formulate water policies have been identified, and finally a comparative evaluation of the current status of progress towards water policies in India, USA, European Union, Russia, South Africa and Australia has been made with reference to 12 parameters.

The eighth chapter is titled 'Sustainability and Sustainable Development of Mineral Resources'. Sustainability of mineral resources is security-centric whereas sustainable development of mineral resources is welfare-centric. The backdrop of growing insecurity about mineral raw material availability to feed the industries has been described in terms of firstly, the conflict between epicurean and environmentalist approaches; secondly, the importance of minerals to human life; thirdly, human resource development; fourthly, growing political unviability of mining projects; and lastly, policy measures. The evolution and diversification of use of the minerals and the role of particularly two minerals, namely aggregates and gold, have been explained with the help of statistical data. This has been followed up by an analysis of the various available options such as military control, recycling, substitution and foreign sourcing. Under sustainable development of mineral resources, issues relating to human health, corporate social responsibility and industrial ethics, business opportunities from closed mines and the sustainable development framework parameters have been described.

The text is followed by Chaps. 9 and 10 and then a glossary. Chapter 9 is a unique one in which over 925 consumer products and processes are listed and against each of them can be found a list of the minerals, metals and rocks as well as the intermediate chemicals and alloys which go into the making of that product or that process. Chapter 10 is a list of about 835 minerals, metals, rocks and intermediate chemicals and alloys and against each of them are listed the names of the end-products and processes for which they are used. Thus, Chaps. 9 and 10 are complementary to each other. If a reader has a consumer product or is concerned with some industrial process, he can immediately find out from Chap. 9 the names of the minerals that are necessary as raw materials for it. On the other hand, if he is concerned with mining or, in any other way, with some mineral or metal or rock, he can see from Chap. 10 the names of the consumer products or industrial processes in which it can be used. These two chapters and the glossary together are expected to serve as a ready-reference material for those concerned with industrial usage of the economic minerals, metals and rocks, and also with the manufactured products and the manufacturing processes. When we talk about the industrial uses of minerals etc., there are three questions to find answers to:

1. What is the use?
2. Why is the use?
3. How is the use?

These chapters readily answer the first question. For the other two, the reader will have to refer to some other books dealing with industrial uses of minerals, metals and rocks.

Now-a-days, the roles of the professionals and the governments concerned with mineral development have gone beyond exploration for and production of minerals and metals. Whenever and wherever an exploration or mining or industrial project is started, it seldom happens that there is no opposition from the local people or environmentalists. In this book no solution is provided because there is no quick-fix solution. The first step towards that is identification of the root of the problems responsible for the perceived threats to shortage of mineral raw materials and to growing insecurity resulting in social tensions world over. The solution will come only through holistic research covering all the natural resources—particularly the competing ones—required by humankind. No such initiative is visible anywhere. This book seeks to concentrate on the first part which is a sine qua non for the second one.

It is primarily targeted to the students, teachers, professionals and researchers in the fields of geoscience, mining engineering and metallurgy as well as those associated and concerned with the industrial use of minerals, metals and rocks.

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Chapter 1
Mineral Resources and Land Cover

The relationship between land and mineral resources is paradoxical. Classical economists have clubbed the two under land resource; thus, at one stroke, refusing to recognize any distinction between the mineral resources on one hand and any other natural resource or man-made commodity on the other. But what is meant by land is its surface and in that sense it is totally different from mineral resource. Firstly, land can be and is divided by boundaries into large and small parcels each of which is associated with individual or collective ownership; secondly, mineral resources are independent of land; and thirdly, land has to be destroyed in order to mine out minerals. Besides, the laws concerning land and minerals have evolved independently.

1.1 Division of Land and Ownership Syndrome

No one person has ever drawn the boundaries on the land. They have been drawn themselves because of interactions amongst groups of humans—either through encounters or wars or negotiations or sorts of quid pro quos. In fact, the animals also have some kind of sense of ownership attached with the places where they live. Habits perpetuated through generations developed into instinct. Birds, after hours or even months of flying, return to the same tree or nest for rest. It is difficult to dislodge a tiger or a lion from its home forest. Snakes, moles and rabbits always go back to their respective holes and bees, wherever they may go in search of honey, will invariably come back to their own hives. This trait was passed on to the prehistoric cave-dwelling humans also. A human would normally not tolerate any intruder to drop in his cave. Again, such ownership seldom went unchallenged and the stronger ones amongst those humans could grab the better and safer dwellings.

In time, the individual humans formed into groups for reasons of security and hunting. A group needed an area around the dwellings. This process accelerated after tonal and verbal communication capabilities developed. But it received the real

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impetus around 8000 BC, when the humans developed agricultural skill and started settling down in groups near river banks. Larger land meant more food not only to satisfy the current needs but also to store for future as the population of a group kept increasing. These groups expanded to form communities and societies and, later on, civilizations. And the initial areas evolved into villages, kingdoms and countries with organized social and political structures, each having its own powerful chief, elite class and working class. The heads decided the division of labour to do multifarious jobs necessary for keeping the inhabitants together and self-sufficient. Most of the works were labour-intensive requiring large number of manual labourers. Besides, the rich kingdoms with abundance of fertile land, food and labourers were at the same time the most insecure ones, being constantly in the eye of predatory kingdoms. Defence was a priority concern of the chiefs who needed to maintain a large army and enough surplus food to feed the army. Consequently, those rich and yet needy civilizations turned predators themselves attacking and conquering weaker ones with a view to acquiring land and capturing men and women to work as slaves. When civilizations advanced, along came mastery over the uses of many other materials in which minerals were the most important. Many battles and wars were fought amongst the civilizations for acquiring control over lands not for their agricultural potentialities but for the minerals that lay underneath.

The earliest civilization was the one that thrived around the valley of Hwang Ho river (Yellow River) in China during ca 7000–6000 BC. The next oldest civilization was the Assyrian Civilization of the central region of Mesopotamia which started rising in 6500 BC, reached its peak during 2300–1760 BC, after which it declined and finally reached its end in 612 BC. Meanwhile, in a region around the Indus Valley (present day Pakistan), the Dravidian Civilization had been rising since 5500 BC and its golden period lasted from 2600 BC till 1900 BC—at the end of which, according to many scholars, a nomadic tribe from Asia Minor (north-east part of present day Turkey) invaded and overran it and started another Great Civilization known as the Indo-Aryan Civilization.

More or less contemporary with the Dravidian Civilization were the Sumerian, Nile Valley and the Persian civilizations. The Sumerian Civilization flourished in southern Mesopotamia, Akkad and Chaldea (southern part of present day Iraq and surrounding regions) during the period 5300 BC to 1700 BC when its place was then taken over by the Babylonian Civilization (1700–600 BC). The Nile Valley Civilization, which started in Ethiopia sometime in the sixth millennium BC, reached its peak in Egypt during 3100–300 BC. The Persian Civilization started rising by 5000 BC, matured during 3200–331 BC and then the Macedonian emperor Alexander conquered and subjugated Persia.

Amongst the next generation of civilizations, the important ones were Minoan, the Phoenician, the Olmec and the Mayan civilizations. The Minoan Civilization thrived around Knossos in Crete Island of Greece during 2700–1450 BC, and it was followed by the New Greek (or Aryan Greek) Civilization. The Phoenician Civilization started rising in 2300 BC in the coastal regions of present day Lebanon, Syria and Israel and was at its peak during 1200–800 BC after which it started declining and finally reached its end in 65 BC. Being born along the Mediterranean

Sea, their people achieved a high level of competency in maritime trade and extended up to Carthage (near present day Tunis). The Olmec civilization of Mexico—famous for its volcano-shaped pyramids—began around 1500 BC and matured during 1200–400 BC when it was conquered by the Mayan Civilization of Yucatan also of Mexico. The latter thrived until 900 AD and spread over a wide area in Central America.

The last ones of the Great Civilizations comprised the Toltec, the Aztec and the Inca civilizations. The Toltec conquered the Mayan Civilization of Mexico and Central America in the tenth century AD and itself was later conquered by the Aztecs in 1300 AD. The Aztecs established their own civilization for a brief period ending in 1521 AD when their land was destroyed, conquered and colonized by Spain. The Inca Civilization started independently in Peru in 1325 AD and it survived till the early sixteenth century. It was also destroyed by Spain.

There were fights amongst and within civilizations; sometimes, a civilization became too large for one ruler to rule; sometimes the ruler of a civilization became too weak to rule his people; many times, a stronger civilization conquered a weaker one and at other times, a civilization broke up into splinters. In the process many old civilizations perished and vanished into oblivion destroying many peoples' old identities and giving them new identities. When these new identities persisted through many centuries and countless generations, the peoples became used to a sense of belonging to and pride for a civilization and the land occupied by it, ready to fight and die for its protection against another civilization occupying another land. In course of time, kingdoms and empires emerged out of the ruins of older civilizations signifying shift of the identity from people to personality. In modern times, especially after the two world wars (1914–1918 and 1939–1945), we see that linguistic, religious, cultural and even personality factors have been outweighed by political factors, and kingdoms and empires have given way to nations and states.

This process of division of the land into countries and of the people into nations lasting through hundreds of centuries have instilled, as we see now, the "my land, my country" attitude in the minds of the people. This attitude has played the most important role in shaping of the preset-day international relationships.

1.2 Land-Mineral Relation

While the land was getting divided and subdivided, the mineral resources remained unaffected because they are independent of land boundaries. The minerals not only lie concealed under the land invisibly but also exist offshore and even in space all along out of reach of the civilizations that divided the land. Offshore, minerals may occur either dissolved in sea water or on the seafloor or deep within the seabed.

Potash and other salts, deuterium and some metals including gold are dissolved in sea water. Besides, fresh water can be and is obtained from seawater by desalination. Furthermore, various forms of unconventional renewable energy (e.g., tidal energy, ocean thermal energy, wave energy) are being harnessed from sea water. On the seafloor are found nickel, cobalt, manganese, iron, copper, lead, zinc, gold, silver and phosphates in various forms like nodules, sulphides etc. besides corals, oyster shells, calcareous material and detrital deposits of monazite, ilmenite, rutile, zircon, garnet etc. The most important minerals in the seabed are methane hydrate (or gas hydrate or clathrate), oil and natural gas. In addition, coal, iron ore, sulphur, diamond and high density brines rich in the metals like iron, manganese, zinc, lead, copper, gold and silver are also occurring.

Insofar as space is concerned, there is unlimited resource of hydrogen regarded as one of the sources of energy in the future. In addition the Moon, the Mars and the asteroids are repository of rich resources of helium, nickel, iron, construction minerals and water. Although these extraterrestrial bodies are also land, they are nevertheless regarded as part of the Common Heritage of mankind.

Another attribute in the relation between land and mineral is connected with the fact that the mineral resources are older than the land of the Earth. According to a recent discovery, at least one mineral namely zircon crystallized even before the process of formation of the land surface was complete. A crystal of this mineral found in Jack Hills region in Australia in 2005 has been geologically dated to be 4.4 billion years old—just a couple of million years after the Earth came into being. However, the surrounding rock i.e. gneiss has been dated to be 3.7 billion years old. This signified that the mineral came into being when the surrounding rock was still in molten state (magma) and 700 Ma later, when the rock solidified, the first land could form there. Formation of land could not precede that of minerals because of the processes involved. The molten mass of the Earth started cooling down from outside and eventually, the surface solidified to become solid rock the surface of which we call 'land'; on the other hand, the primary minerals crystallized in a matrix of magma deep inside the Earth and then were carried upwards by volcanic eruptions.

1.3 Land and Mining

It becomes apparent, therefore, that the land has to be dug and destroyed for taking out the minerals lying underneath. Pieces of minerals may, of course, be strewn on the land and can simply be picked up without digging. But, as a rule, it is necessary to first reach the mineral body by excavating a quarry, sinking a shaft or driving an incline or adit. In the process, the land along with the trees, hills, buildings etc. on it gets destroyed. This may at times be in direct conflict with the overground political boundaries of land. It may happen—intentionally or unintentionally—that the miners of one country may get into and mine out the mineral resources of another country underground. It is alleged that in the 1980s, Kuwait exploited oil this way from under the soil of Iraq.

Although a running mine keeps on destroying the land, in the long run it may also add value in a different way. About 150-year old Chile saltpetre mines of Humberstone and Santa Laura located in Atacama Desert in the north-eastern area of Chile have been declared by the UNESCO in 2005 as World Heritage sites after which they attract tourists. However, the best example of mine tourism is served by the 700-year old Wieliczka rock salt mine (started in 1288) just outside the city of Krakow in Poland. The mine, included in the UNESCO World Cultural Heritage list, has a labyrinth of tunnels—300 km total length—and has, at present, been producing approximately 100,000 tonnes of salt annually from a depth of about 350 m. It is renowned for its various structures carved out of the salt during mining—a chapel with chandeliers, altarpieces (all carved out of salt), cafes, toilets, a museum, and a sanatorium where beds are booked long in advance and where asthma patients spend a few days to get relief from the salty and humid atmosphere. Around half a million people visit the mine each year. But such fortune befalls a mining land rarely and that too after many years of mining. In terms of a few generations, mining is destructive to the land.

The laws governing ownership of lands and mineral resources are different. Lands are owned by governments or private citizens or institutions. The tradition of private ownership of land may be traced back to the times when the humans were taking to settled lives about 10,000 years ago. But mineral resources are, in most countries, owned by the governments and the miners can take them only on lease for fixed tenures.

1.4 Value of Land

The area of the land is finite, but its economic value does not lie in the surficial extent. The value of a land is determined by its utility which manifests itself in the form of agricultural potentiality, forestry, residential construction, industries set up, mineral resources underneath and so on. In the primitive era, land was valued for animals by the primordial humans depending on how rich it was with regard to games to hunt and fruits to gather. The criterion continued to be food after 8000 BC which is generally accepted as the year when the humans learnt to domesticate wild grains, took to agriculture and settled down in groups in fertile lands. So much so that with a view to acquiring control over more and more fertile land, the groups fought fierce battles amongst themselves. Somewhere up the time scale, when minerals and the metals extracted from some of them became the basis of a nation's economic and military strength (even for enhancing and storing agricultural produce), the value of land shifted to the mineral resources that lay underneath.

The earliest recorded evidence of conquering a foreign land solely for some minerals (apart from slaves) dates back to late pre-Christian and early Christian era. Around that time the Romans invaded Cornwall for salt—a highly valued strategic mineral in those days. They conquered Spain, Portugal and England also for acquiring control over the resources and mines of gold, silver, mercury, tin, copper, lead and iron. Of these, Spain was the most mineralized region known then and the Romans got most of their fabulous wealth from there.

Venice fought three wars against Genoa (the last one in 1381) for gaining control over the European salt-trade through the Mediterranean Sea. The salt was then a vital strategic mineral for preservation of food of the soldiers fighting away from their homes through weeks and months at a stretch. Towards the end of the nineteenth century, two bitter wars were fought in South America over control of mineral resources. One was the Chincha Islands war which raged between Spain on one side and Peru and Chile on the other over possession of Chincha and certain other islands off the western coast of South America which were rich in guano—a fertilizer mineral in those times. The other was the War of the Pacific between Chile and the joint forces of Bolivia and Peru for possession of the world's largest resource of the mineral 'Chile saltpetre' in Atacama Desert located in the border zone of Chile, Peru and Bolivia. Till the 1940s, Chile saltpetre was a highly sought after mineral because it was a key ingredient in explosive besides being a fertilizer and a food preservative.

Diamond has earned the sobriquet 'blood diamond' in certain African countries. For acquiring desperate control over the lands rich in diamond resources, attacks and counter attacks by the governmental and the rebel forces have been going on in Democratic Republic of Congo, Angola, Liberia and Sierra Leone since the last quarter of the twentieth century. The rebels try to mine and sell the diamonds for buying arms and ammunition and the governments try to stop them from doing so. In the first decade of the twenty first century, it is believed that the Swat valley of Pakistan, where a lapis lazuli mine is located, was the target of the rebel forces.

The seabed below the Arctic ice is believed to be rich in oil—the single most crucial mineral the countries and the people cannot do without today. Since the Arctic ice is now melting very fast due to global warming, the eight Arctic countries namely Russia, Canada, USA (Alaska), Norway, Sweden, Denmark (Greenland), Finland and Iceland have now set their eyes on the 'ice-free' Arctic Ocean for their share of the land and the oil underneath.

During the 1990s, two wars were fought between Iraq on one side and Kuwait backed up by US-led forces for control of oil. In 2011–2012, tension and stray battles have been raging between Sudan and South Sudan over the possession of the oil town of Hegjig on as-yet-undefined border between the two countries. More recently, in 2012, when Afghanistan has been found to be rich in the resources of oil, copper, gold, iron ore, lithium etc. powerful regional warlords there have started trying to aggressively expand their territories to include areas with mineral wealth.

Today, however, the value of land does not depend on food-producing and mining potentiality alone. There are other land-uses too which influence the value of a land. These include:

1. Forests
2. Industries
3. Residential buildings
4. Bio-fuel cultivation (oil palm, corn, jatropha etc.)
5. Freshwater source (rivers, lakes, groundwater aquifer etc.)
6. Roads and communication

7. Parks and gardens
8. Recreation centres
9. Archeological and historical ruins
10. Utilities (markets, hospitals, schools, universities etc.)
11. Funeral sites

However, all these criteria notwithstanding, concerns of the common people about food, mineral and energy securities have become so desperate that some people have embarked on a land-grabbing spree in whichever country the conditions are favourable with the motives of profiteering and speculation. Some governments are also either encouraging or indulging themselves in such activities for ensuring security of their own people. During the Mediaeval period, some European countries colonized the countries of Asia, Africa, North America and South America for acquiring control over the resources of industrial raw materials—minerals, cotton, indigo etc., with the motive to sustain their industries and thereby accelerate their economic growth. By the end of the twentieth century, practically all the colonies have become independent. But now the same spirit seems to have returned in a different form. According to Washington-based World Watch Institute, between 2000 and 2011, a total of 70.2 million hectares of land worldwide have been sold or leased to private and public investors mainly in the low-income countries of Africa (Democratic Republic of Congo, Angola, Ethiopia, Mozambique, Nigeria and Tanzania, Zambia and Madagascar) and S-E Asia (Indonesia, Thailand and Laos). These lands are mainly agricultural, but include some rainforest and wildlife habitat also and they account for 1.4 % of world's 5 billion hectares agricultural land. This trend of land-grabbing spree has been particularly driven by the emerging economy countries. These countries are beset by problems of widening gap between demand and supply of energy, large population and shrinking area of arable land and consequent vulnerability to financial and food crises and yet they are racing to catch up with the developed countries. The three countries—India, Brazil and China—accounted for as much as 24 % of this land grab. Besides, some British firms and Saudi Arabia were also among those in the fray.

1.5 Law Relating to Land

The land ownership concept has developed through wars amongst groups, civilizations and, later on, kingdoms and nations and it has been firmly ingrained in the minds of individuals and families through generations. System of land records started in organized civilizations. Ownership was already in place, records and documents were made much later to regularize those ownerships. Naturally, in case of the tribals and aboriginals, the limits of ownership have not been recorded in any map or document but are known as a matter of understanding in the respective communities. Even in many organized civilized societies, land records are not up to date. This is the situation in India because here, countless kings and feudal lords of the past gave away lands—both residential and agricultural—to people as reward for some good deed, in return for some service or payment and so on. Distant forefathers of the present generation of people might have got lands many centuries ago and the ownership has been perpetuated through their descendants. Perpetuation of ownership through generations is an important attribute of land. This perpetuation has created many intermediary interest-holders to such an extent as to make the process of division of land amongst the heirs of a deceased owner fraught, at one stage or other, with litigation. The system of land records has still not become conclusive and it continues largely to be presumptive.

The second attribute is the owners' emotional attachment to their respective lands—particularly the lands where they are residing or farming. This may not be the case in highly materialistic societies, but is true for a large population living in the developing countries like India. For such people, land has become an integral part of the family and for them family means not just the present generation. Their emotional attachment is in the same way as they are attached to their parents and children.

The third attribute is that land is not only a source of livelihood for the family members of the owners but also a cornerstone of financial security. In a country like India, nearly 60 % of her 1.2 billion citizens depend on farming for a living and, on an average, each hectare of farmland supports five people. Besides, land-holding is a mark of social standing of the owner.

Fourthly, the monetary value of land, as has already been said, lies in its utility. Utility may change unpredictably with time and so does the monetary value. Today, an agricultural land in a remote inaccessible area may carry a certain low value, but tomorrow if infrastructure and industries come up in the vicinity, the value may increase several fold. Even if the land remains agricultural, its value may change according to the level of irrigation, the nature of cultivation and the type of produce. This element of unpredictability in the status of land-use and, consequently, monetary value of land create most of the legal complications in land acquisition for industrialization.

Fifthly, there is no free land market as such where both demand and supply have a free play to determine price. In this case there is no flexibility in the supply of land as such whereas its demand can go up or down depending mainly on the buyers' income. This absence of land market combined with its scarcity and the unpredictability of its monetary value has made land an ideal object of speculation.

These attributes make land acquisition for mining or any other industry extremely difficult in developing democratic countries with high population density as in the case of India. Buying a land here leads to buying the litigation attached to it and, over and above this, any land deal has become a politically hypersensitive issue. The Constitution of India has accepted the right to property as a fundamental right of citizens and as in the case of any other fundamental right, this right has also changed the focus from state-dominated interest to people-centric objective. Under this Constitution, land is a state subject but land acquisition is a concurrent subject falling under the jurisdiction of both the state and the central governments. The general principle of estate acquisition is based on 'eminent domain' which means absolute power of acquisition and requisition of any property for the use of the state in discharging its sovereign functions. But acquisition of agricultural land owned by village folk has always been a ticklish issue in a developing democratic country like India because there is asymmetry of power and information between those wanting to acquire the land and those whose lands are being acquired.

The land, in India, is classified into tenancy land and government land; the latter may be forest land or non-forest. Transfer of government land is relatively easier. But it is the tenancy land which is the most problematic because its acquisition involves displacement of the occupants. The land acquisition here is governed by the Land Acquisition Act, 1894. According to this Act, the purposes of land acquisition include public interest and for use of companies. But public interest has not been defined and is presently open to interpretation in various ways. It is possible to establish public interest for using the subterranean mineral resources as also for constructing infrastructure (roads, ports etc.), for building utility centres (hospitals, schools etc.) and for generating agricultural goods irrespective of whether the activities are by the Government or some private company. This is one of the reasons why land disputes in India do not get resolved quickly.

The above Act of India is now being amended so as to give exclusive right to the State in matters concerning land acquisition while at the same time striking a balance between the State's role and consent of the land-holders. From the amended Act will be excluded various activities like mining, highway construction etc. for which there are separate acts. Another important feature of it is the incorporation of obligatory provisions of relief and rehabilitation of the ousted people. And similar provision in the other acts governing mining etc. may be made in the future.

Therefore, in reality mineral resource is not part of the land resource, the two being independent economic as well as legal entities contrary to what some economists contend. The prices of mineral commodities are guided by the law of demand and supply to a greater extent than land and the two resources are governed by separate sets of laws all over the world.

Chapter 2
Minerals and Other Economic Entities

The mineral resources compete with other resources. But in this competition there is no winner or loser from the point of view of utility to the humans. All resources are useful and it is difficult to pinpoint any one of them as more useful than others. Nevertheless, competition is for the same piece of land because, as a rule, development and/or exploitation of all resources will have to be related to land the exception being the resources in seawater and space. While the mineral resources are underground resources, all other resources are overground.

2.1 Mineral Resources

There are some special and unique characteristics of mineral resources found in no other resource—natural or manmade. These characteristics are as under:

1. Minerals are basic to the survival and civilization of man, all other outputs (including agricultural and industrial) being the result of interaction between human and mineral resources. In fact, as long as there is life on the Earth, the minerals will be needed—mined or unmined. The history of use of minerals by man is as old as the Palaeolithic era—long before man came to learn about and started practising agriculture. Today, minerals are the ultimate raw material for anything and everything that the humans consume (see Chaps. 9 and 10). Economic value of mining and minerals is substantial and they create a multiplier impact on economies that go for downstream processing. Smelting and refining capture value while manufacturing is the key to maximization of value from mineral resources. For the humans, this whole process has not only huge economic benefits but also social benefits including productive employment.
2. Mineral resources are finite and non-renewable while other tangible natural resources like forest, wildlife etc. can be created by man and hence are renewable.

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3. Mineral resources are invisible, being hidden under the surface of the land while other resources like forest, wild life, agricultural crop, factories etc. are all visible, being on the surface.
4. Being underground, mineral resources have the depth dimension in addition to the lengths and widths.
5. A mineral deposit, if not exploited, remains a perpetual asset. Even catastrophes like earthquake and tsunami cannot destroy a mineral deposit; they can, at the worst, alter their location and configuration. Most of the mineral deposits are also immune to fire, only exceptions being coal, petroleum and natural gas. It is true that fire can destroy these minerals; but it is also true that there is no chance of natural fire underground. Fire can only break out due to anthropogenic causes.
6. Mineral deposits are creations of nature and hence, the vagaries of their physical characteristics and chemical qualities have to be accepted as endowed by nature; any improvement is possible through processing only after mining. This implies that the choice of raw materials for the mineral-based industries is extremely limited and the technologies for processing of the minerals have to be adopted according to the natural quality of the available mineral raw materials and not the other way round. There is another economic fallout of the natural physical characteristics which can be explained with the help of examples of two minerals namely hematite and chromite in India.

   Hematite occurs in nature as compact lumps and as friable ore which crumbles to fines while mining, their ratio being 1:2–1:3. Demand within India is for lumps but for every tonne of lumpy ore 2–3 tonnes of fines will automatically be produced resulting in accumulation of hundreds of thousands of tonnes of fines at mine-heads. The problem of chromite in Odisha is similar except that the ratio of lumps to fines is 1:4. The solution, of course, lies in agglomerating and then using the fines. But the benefit-cost comparison is between exporting the fines and exporting the energy-intensive agglomerates (sinters, pellets). In 2012, the Government of India has taken some policy decision in favour of exporting pellets by reducing the export duty on pellets and increasing that on ore.
7. Mineral deposits are location-specific and have to be mined where nature has created them. Nature has created mineral resources in certain locations with favourable geological environment. Certain minerals are highly localized so as to give almost monopolistic power to a few select countries. Oil is a typical example of such minerals. Its resources are hugely concentrated in the Middle-East region and a few other countries which, having exportable surplus, feed practically the whole world. Most of these oil-rich and oil-exporting countries have formed a cartel (Organization of Petroleum Exporting Countries or OPEC). This cartel dictates the price of oil in the international market holding the oil-importing countries practically at its mercy. And this situation has made oil a speculator's favourite commodity. Due to such localization of minerals a situation has arisen where no country is self-sufficient in all the minerals that are needed. Every country has to import some minerals in exchange of export

of some other commodities in which it has abundant resource. Taking the same example of oil, the Middle-East countries have to export it so that they can import other commodities. If for some reason the UN imposes sanction on any such country, its economy becomes vulnerable. In 2012, this has happened with Iran and earlier, with Iraq—both oil-exporting countries.

8. While land supports other natural resources and man-made assets and its morphology remains intact, land has to be destroyed for exploiting mineral resources. In fact, minerals present underneath a land support forests and agriculture by supplying the nutrients.
9. Mineral resources, like rivers, are independent of political boundaries and they may extend under the ground across international boundaries—unknown to the peoples and governments.
10. The gestation period for developing a virgin mineral deposit to production stage is longer compared to other commodities. Laws of India allow a maximum of 10 years for this purpose after getting the permit—3 years for reconnaissance, 5 years for prospecting and 2 years for mine development. But before the grant of permit, a host of clearances including environmental, forest etc. and other procedures take 5–8 years. And in case the land is subjected to litigation, this period may be much longer. The total gestation period from application for reconnaissance permit to production in a mineral property may go up to anything like 15–20 years or even more (in case of a uranium deposit in Meghalaya in India, over 30 years have passed since the exploration was carried out and till March, 2013 it has not come to the production stage). The American petroleum geologist M. King Hubert, who is credited to what has become famous as the 'Hubert's Curve' for forecasting peak petroleum production, analyzed the history of discovery of oilfields and oil production in US and concluded that the production curve will match the discovery curve with a 30–40 year lag. Due to this long gestation period of mineral development, the response time of supply to a new demand is much longer compared to other commodities. Obvious fallout of such supply constraint is that the price becomes hypersensitive to demand.

Demand is the prime mover of all economic activities and not exclusive to those concerning minerals. But in case of minerals, demand—not just for minerals directly, but for any mineral-consuming commodity—sets in motion an activity which is exclusive to mineral resources i.e., exploration. Mineral resources, being hidden deep under the ground invisible to humans, cannot be measured or weighed or counted through surveying unlike forest areas, agricultural crop or wildlife. Their extents, quantities and qualities can at best be estimated indirectly by the process called exploration. The invisibility and uncertainty are responsible for low success ratio of identifying mineable resources. In case of oil, the average success ratio of discovery is 10 % and as regards granite (dimension stone) in India the probability of striking a mineable deposit is 25 %.

The uncertainties about geological nature, quantity, quality and usability of minerals have modified significantly the economic principles and theories applicable to minerals vis-à-vis other commodities like food grains, forest produce etc. For example, the theory of competition as generally understood and as holding good for different commodities does not apply to minerals. Mineral deposits being natural and deep seated are controlled by geological parameters; and the cost of production of a mineral cannot be reduced by human efficiency beyond a point, after which geological factors become more important in determination of the cost. It has happened in case of Mosabani copper mine of India which has closed down in 1996. The depth of mining had increased to over 600 m and, the grade had been decreasing with depth. When the mine started in 1928, the copper content of the ore was over 2 % which decreased to barely 1 % by 1996. Compared to this, the centuries old Chilean mining industry—the biggest player in the international market—was producing higher grade ores from mines some of which were opencast. For example, the ore from 300 m deep opencast mine Escondida (world's largest) contains 1.51 % copper; that from 850 m deep Chuquicamala underground mine contains 2.58 %; and the ore of a yet-to-start Illapel project has been analyzed to contain up to 5.5 % copper with an average of 4 %. There is no way that the copper produced from the Mosabani mine could compete with that from Chilean mines.

Exploration is a high-risk zero-return technology-intensive and costly activity. Risk is on account of success ratio of discovering a mineral resource and then delineating minable reserves within the resource. It is zero-return because monetary return can come only when mining starts long after exploration is completed.

The depth dimension calls for special technologies for exploration and mining. Drilling is the most common technique of exploration of a deposit—whether shallow or deep. Special techniques are needed for drilling for oil which may go down to depths of several 1,000 m (till 2012, the deepest offshore wells were 12,345 and 12,289 m from the sea surface in Sakhalin, Russia and Al Shaheen, Qatar).

As regards mining of solid minerals, the techniques are different for shallow and deep deposit. In the former case, opencast and in the latter case underground mining methods are practised. The deepest metal mines are the East Rand and Whitewater Sand gold mines of South Africa which have reached depths in the range of 3,500–3,600 m. But for ocean mining, special submersibles are deployed and research and development are underway in countries like Canada, Japan, Korea, China and Russia to use other technologies (a Canadian company is planning to use an 1,800-m-long hose for vacuuming up metal-rich silt from the bottom of Red Sea). While China is in possession of a manned submersible, which by 2012 reached depths of more than 7,000 m below sea level; USA, Japan, France, Russia and India have automatically controlled submersibles having capabilities to reach depth ranging 6,000–6,500 m. Such deep mining would require 4-days modelling, artificial intelligence, tele-mining, endoscopic mining and integration of mining with information and communication technology or ICT. All these would involve processing and storage of enormous volumes of data requiring highly advanced system capabilities (e.g., robotics, petaflop computers, etc.). In the Swedish conceptual study 'Smart Mine of the Future', it has been envisioned that the answer would lie in continuous mechanical excavation, no human presence in the production area, and pre-concentration.

The requirement of land for scientific mining depends on two parameters:

1. Plan area of the mineral body
2. Method of mining which depends on the depth of the mineral body

For mining a large deposit with large plan area, commensurately large area land will be required. Otherwise the whole of the mineral resource cannot be exploited and considerable portion of the precious non-renewable gift of nature will be wasted. As regards method of mining, opencast mining requires large land while underground mining needs relatively smaller area irrespective of the size of the deposit. It is obvious that for scientific mining purpose, the division of land should only be on the above considerations and not on any other. And for the knowledge of both these parameters—plan area and depth—prior exploration by drilling etc. is sine qua non.

Concerns for industrial raw materials security have reached such a proportion that intensive research is going on in United States and some other countries for achieving capabilities of extraterrestrial mining. The Moon, the Mars and the many asteroids are rich in the resources of certain minerals like helium, nickel, iron, construction materials etc. Exploration and mining in these celestial bodies will require not only totally new technologies but also machines made of advanced materials.

2.2 Overground Economic Entities

Land is the common factor between the underground mineral resources and the overground economic resources. Consequently, there will have to be claims and counterclaims for exploitation in the same land. Additionally, there is competition amongst the various overground resources and also within some individual overground resource. These three levels of competition for the same land have complicated the politico-economic climate of today. To add to the complication, these entities are governed across the world by different sets of laws.

The overground resources can be broadly grouped under the following categories:

1. Agricultural produce
2. Forest and wildlife
3. Biodiversity
4. Human settlement
5. Industries
6. Real estate
7. Environment

There is another kind of overground natural resource which has assumed enormous importance now-a-days. This is the data communication spectrum. However, this does not interfere with exploitation of any land-based resource; on the contrary, it helps the exploitation processes.

2.2.1 Agriculture

Food security will be one of the major challenges worldwide in the years ahead. According to Food and Agriculture Organization, the global food demand forecast will rise by 70 % by 2050 accompanied by a steep increase in the demand for feed, fibre and biomass. But this challenge is becoming all the more formidable due to expansion of industries and human settlements at the cost of shrinking of arable land, deterioration of soil quality by overuse of chemical fertilizers and insecticide in many parts of the world (e.g., Europe), uncertainty of monsoon in the tropical countries like India, lack of adequate investment in irrigation facilities in countries like India where agriculture is dependent mainly on rain. The alarming trend of decline in the population of the farmland birds over the last 50 years indicates deterioration of the general quality of farming environment. In Europe the population of various farmland birds like white grey partridges, turtle doves, wood pigeon, lapwings etc. has declined by up to 50 % between 1966 and 2011. These birds feed on weeds and the variety of seeds available in environment-friendly farms. Monoculture farming and use of insecticides and weedkillers are believed to be the chief causes. In short, the challenge is not only to produce more but also to produce in a sustainable manner i.e. securing and maintaining the soil functionality.

Next to minerals, agriculture was the first economic activity of the humans when they took to settled life circa 10,000 years ago. In India, agriculture along with its allied activities is the lifeline of economy because:

1. It accounts for 19 % of the GDP.
2. It employs over half of the country's total workforce.
3. Farm produce accounts for 11 % of the exports.
4. Farm sector provides raw materials to certain industries (e.g., textile, paper, brewery, sugar).
5. Good harvest means disposable income for a large population of farmers who thus get more to spend.
6. Cheaper food means that the city-dwellers have more money to spend and save.
7. More disposable money with both the rural and urban population spurs demand boosting industrial production.

Agriculture is renewable and its gestation period is the shortest amongst the resources, a few months upwards. But it depends on rain—directly or indirectly—particularly in some tropical countries where agricultural economy is dominated by monsoon. In case of non-irrigated land, the dependence on rain is direct whereas in case of irrigated land, the water is sourced to the water reservoirs which are filled up by rain or rivers fed from rain in the catchment areas. Even the rivers, which are of glacial origin, collect rainwater during their courses. In non-irrigated land, agriculture may also be sustained with the help of ground water which again depends on rain for recharging. According to a World Bank report, in India, irrigated land constituted only 34.66 % of the total agricultural land in 2008 and it marginally improved to 35.12 % in 2009. The uncertainties of weather combined with the fear of the adverse effects of global warming have created a near-panic situation underscoring the peoples' hypersensitivity to food security. During 2007–2009, three consecutive years of drought in Australia, which had all along been the principal rice supplier in the international market, engendered failure of Australia's rice production by 98 %. This resulted in doubling of international price of rice and there was panic accompanied by violent protests and riots in countries as far away as Haiti, Cameroon, Egypt, Ivory Coast, Mauritania, Senegal, Italy, Yemen and Thailand.

While agriculture competes with mining for land, there is competition within agricultural sector between food grain cultivation on the one hand and cultivation of agricultural raw materials for industries and fuels on the other hand. Nowadays even bio-fuel plants are competing with food crop plants in the same fertile land (bio-fuel plants like corn, oil palm, jatropha etc. are sources of a kind of vegetable oil which can substitute mineral oil). In US, diversion of substantial agricultural land for corn cultivation triggered a shortage of food grains and public outcry in 2008.

Unlike mining, agriculture has practically unlimited flexibility with regard to area of land-holding.

2.2.2 Forest and Wildlife

Forest and wildlife are inseparable. For the humans, they contain both tangible and intangible economic values. Food, medicine, timber, paper, foot-wears etc. are derived from the trees, animals and birds. The tangible value can be converted into money. But the intangible value which pertains to the lives of the animals as well as the emotions of the forest-dwelling tribals and the outside humans cannot be measured in terms of money. Death of any animal species disturbs the natural balance. As regards the tribal people, they have not so far fully graduated to the stage of agricultural economy unlike the non-tribal village folk; and their economy is a complex mix of all stages of human progression from hunters and gatherers through pastorals, shifting cultivation and settled agriculture. In other words they derive their subsistence from the entire habitat and in the event of displacement, their emotional bondage to their culture, traditions, community and, more importantly, their pride, dignity and ethnic identity are destroyed (the latter, in particular, is the cause of many conflicts, violence and riots on the issue of land encroachment in India). Furthermore, in India, the descendants of some trees, which were once associated with ancient saints, are considered sacred and worshipped. What's more, they perform an important function for man—transforming rocks into soil.

However, forests can be re-grown at a new place and wildlife can be translocated, but it requires favourable soil and climate. Gestation period for growing a new forest may vary according to the species of the trees. For certain fast growing trees, it may be as short as a couple of years. But for wildlife to thrive, a variety of trees will be required. Consequently, the total gestation period may grow up to 5–10 years. And rehabilitation of wildlife can start only after a forest is fully ready and also the area is large enough. According to the Wildlife Institute of India (WII), for every 20 breeding tigresses, an area of 800–1,000 km^2 is required to be maintained inviolate. However, problems arise about the tribals living in a forest. Rehabilitation of tribals in an alien place is fraught with many problems and is now-a-days the cause of most of the problems when mining or any other industry is created in a forest area.

Many countries recognize the importance of forests for the survival and wellbeing of their people and have laid emphasis on conservation of forest. The somewhat contrary policies in India and Australia along with the norms of the International Union for the Conservation of Nature (IUCN) are discussed below.

2.2.2.1 Indian Policy

At the end of 2010, India had a forest cover 23.4 % of the land area vis-a-vis her goal to gradually increase to 33 % in the plains (in the hills along the Himalayas, the goal is 66 % and the achievement has by and large exceeded it). One of the steps in this direction is based on net present value (NPV). For this purpose, the forest has been classified into various types and eco-classes. The first level of classification, based on canopy cover, is into three types namely:

(i) Very dense forest land (canopy cover above 70 %)
(ii) Dense forest land (40–70 % canopy cover)
(iii) Open forest land (10–40 % canopy cover)

Each type is further classified into six eco-value classes as follows:

Class I: Tropical wet evergreen forests, tropical semi-green forests and tropical moist deciduous forests
Class II: Littoral and swamp forests
Class III: Tropical dry deciduous forests
Class IV: Tropical thorn forests and tropical dry evergreen forests
Class V: Sub-tropical broad-leaved hill forests, sub-tropical pine forests and sub-tropical dry evergreen forests
Class VI: Montane wet temperate forests, Himalayan moist temperate forests, Himalayan dry temperate forests, sub-alpine forests, moist alpine scrub and dry alpine scrub

NPV of the trees cut is calculated on the basis of (i) value of timber and fuel wood, (ii) value of non-timber forest produce, (iii) value of fodder, (iv) value of eco-tourism, (v) value of bio-prospecting, (vi) value of ecological services of forest, (vii) value of flagship species and (viii) carbon sequestration value, and the NPV depends on the forest type and eco-value class. The NPV per hectare of forest in India has been fixed by law as shown in Table 2.1.

Table 2.1 Net present value per hectare of forests as determined and enforced in India (*Value in INR*)

	Very dense forest	Dense forest	Open forest
Eco-value class I	1,043,000	939,000	730,000
Eco-value class II	1,043,000	939,000	730,000
Eco-value class III	887,000	803,000	626,000
Eco-value class IV	626,000	563,000	438,000
Eco-value class V	939,000	845,000	657,000
Eco-value class VI	991,000	897,000	699,000

Table 2.2 Categorization of the protected area of the IUCN

Category	Type of the entity	Definition
I	Strict nature reserve/ wilderness area	Areas of land or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring. These are largely unmodified land or water retaining their natural character and influence without permanent significant habitation which are managed mainly for science or wilderness protection.
II	National park	Areas of land or sea designated to (a) protect the ecological integrity of one or more ecosystems for the current and future generations, (b) exclude exploitation or occupation inimical to the purpose of designation of the area and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.
III	Natural monument	These areas are protected mainly for conservation of specific natural/cultural features which are of outstanding or unique value because of their inherent rarity, aesthetic qualities and cultural significance.
IV	Habitat/Species management area	These comprise the areas of land or sea which are subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of particular species.

2.2.2.2 IUCN Norms

As per these norms the corresponding term for the ‘Reserve Forest’ in India is ‘Protected Area’. These areas comprise the areas of land and sea especially dedicated to the protection and maintenance of biological diversity and natural and cultural resources which are managed through legal or other effective means. These reserves are further categorized as I, II, III and IV (Table 2.2).

In the IUCN norm, there is no mention of any provision of economic exploitation of the Protected Areas.

2.2.2.3 Australian Policy

In contrast to the Indian policy, the National Forest Policy Statement (NFPS) of Australia has adopted region-specific goals and also clubbed biodiversity (see later in this chapter) with forest. This forest conservation framework is called Comprehensive, Adequate and Representative (CAR) System for Forests in Australia and is characterized by:

(i) Comprehensiveness: It includes the full range of forest com-munities.
(ii) Adequacy: The ecological viability and integrity of populations, species and communities are maintained.
(iii) Representativeness: The selected forests reasonably reflect the biotic diversity of the communities.

While practically applying this system, the principles adhered to are as follows:

(i) Conservation effort is focused on regional priorities and not based solely on meeting percentage targets.
(ii) Need for flexibility to allow changes to the CAR system as a result of changes in knowledge and changes in biota (such as through climate change).
(iii) Utilization of the best available data in each region including local expertise and knowledge.
(iv) Integration of conservation requirements with social and economic considerations which include benefits accruing from non-timber uses of reserves and costs associated with industry adjustments and resultant impact on employment.

For the implementation of the CAR system, the land has been broadly classified as follows:

1. Public land
   (a) Dedicated reserves: This is equivalent to the 'Protected Area' of the IUCN.
   (b) Informal reserves: These include areas which cannot be managed through legal codes but otherwise possess same conservation values as the dedicated reserves. Such forest areas are managed through some other secure tenure management arrangements.
   (c) Land having values protected by prescription: These values include those with fragmented distribution, those naturally occurring in linear form (e.g. riparian vegetation) etc. protection of which is prescribed by other management codes.
2. Private land: Many of the most threatened forest species and ecosystems throughout Australia occur in private lands. Mechanisms to protect them include purchase of priority areas, development of incentives, covenants etc. However, since the level of protection is limited, conservation efforts are focused only on the priority forest species and ecosystems.

In all classes of land, certain criteria are applied which are centred on flexibility varying from region to region. These criteria are as follows:

(i) Biodiversity criteria: Not everything is required to be reserved. The priority for reservation of a forest ecosystem depends on how much remains relative to the initial distribution and its vulnerability to threat. The cut-off year is 1750 (year of beginning of European settlement). As a general criterion, 15 % of the pre-1750 distribution of each forest ecosystem should be protected with flexibility considerations applied according to regional circumstances. But where forest ecosystems are significantly threatened or are approaching 70 % reduction in areal extent, then at least 60 % should be reserved.
(ii) Old-growth forest criteria: An old-growth forest is defined as a forest that is ecologically mature and has been subjected to negligible unnatural disturbance such as logging, road construction etc. It can have a high value of a range of biological, aesthetic and cultural significance. Where old-growth forest is rare or depleted to less than 10 % of the extant distribution, protection should be 100 % and in other cases, 60 %.
(iii) Wilderness criteria: Wilderness is a cultural concept which relates to large areas of usually undisturbed land free from the influence of European settlement. Such areas provide opportunities of solitude and self-reliant recreation. Their protection is left to the regions, and so are the guidelines regarding extent of land to qualify as wilderness which is generally 8,000 ha plus or minus.

It is apparent that under the CAR system, considerable flexibility is provided to the regions for deciding the extent of area to be protected; the pre-1750 distribution of each forest ecosystem, depending on the regional factors and the areas available for exploitation, may range up to 85 %.

2.2.3 Biodiversity

In India's National Biological Diversity Act, 2002, which is administered by the National Biodiversity Authority, both biological resource, and biological diversity or biodiversity have been defined as under:

(a) Biological resources means plants, animals and micro-organisms or parts thereof, their genetic material and by-products (excluding value added products) with actual or potential use or value, but does not include human genetic material.
(b) Biological diversity means the variability among living organisms from all sources and the ecological complexes of which they are part and includes diversity within species or between species and of eco-systems.

Under this Act, there is the National Lake Conservation Plan (NLCP) for conservation of aquatic biodiversity of the lakes. Recently it has been proposed that the scope of this plan will be expanded to include wetlands and to re-designate the plan as National Plan for Conservation of Aquatic Ecosystem or NPCA (*Hitavada*, Feb. 8, 2013).

Every habitat—ocean, polar ice, forest, tundra, desert, lake, river, mountain, wet land etc.—supports an ecosystem and a biodiversity of its own. These ecosystems with all its biodiversities make up the ecological balance of the Earth. The species include trees, plants, birds, insects, fungi, microorganisms, and worms all of which in one way or other help pollination and reproduction of the trees and plants and they also provide nutrients to the soil. Thus the forests are sustained. The insects, birds, herbivorous animals and carnivorous animals help check the overgrowth of the population of different species and the scavenger animals and birds (e.g., hyena, vulture) naturally maintain cleanliness. Formation of soil from rocks is a complex process which is facilitated by many organisms. Plant roots break up rock to create soil particles; earthworms, mites etc. help give soil its texture and fertility and are crucial to its aeration; tiny microorganisms and fungi are responsible for recycling essential nutrients like nitrogen, phosphorus, potassium, sulphur etc. making them available to plants. It is therefore obvious that even a slight imbalance of the biodiversity would disturb the balance of a number of parameters like climate, oxygen, food, water, health, economics etc.

2.2.4 Human Settlement

Human settlement includes towns and villages along with various utilities (e.g., railways, roads, electricity and water distribution network etc.), social infrastructure facilities (e.g., hospitals, schools, universities etc.), places of worshipping, funeral sites, archaeological and historical ruins, parks and playgrounds, entertainment houses, markets etc. The tiny settlements centred on fertile lands 10,000 years ago evolved to villages and then to towns along with a few utilities like roads, places of worshipping, funeral sites and markets. All the other components were consciously created by the people of the towns and villages and their creation received a boost after the industrial revolution in the second half of the eighteenth century. Such settlements occupy large tracts of land, for which they compete with the aforesaid entities.

The real problem started after the industrial revolution in the second half of the eighteenth century. Within a short time thereafter, industries started multiplying, international trade grew in leaps and bounds, a section of the people became rich suddenly and there was population explosion. According to the most conservative amongst various estimates including that by the UN, the world population during the 300-year period 1,500–1,800 grew from 425 million to 813 million i.e., at an average annual rate of 0.3 % whereas the growth during the 200-year period 1,800–2,000 was from 813 million to 6,080 million i.e., at an average annual rate of 3.24 % and the population is projected to reach a level 9.35 billion by 2050. This increase in population naturally increased both the areas and the numbers of villages and towns exerting pressure on the finite land.

Theoretically, villages and towns are not location-specific as the mineral resources are. But in reality, a vast majority of them has evolved naturally starting from the stage when the humans were still hunters and gatherers just as some primitive tribals living in their settlements are even today. As the humans gradually underwent transition to agriculture-centric lives, those tribal settlements evolved to villages and then to towns. Many new towns have been and are being built by the humans through conscious endeavours and their gestation periods are quite short. But most of them are built either on some pre-existing villages or as extensions of some pre-existing towns.

The crunch is not yet a global problem. But it is becoming more and more visible in the countries with large population and high population density. Table 2.3 shows the population densities of some industrialized and some developing countries.

Table 2.3 Population densities of selected industrialized and developing countries

Country	Total land area	Population density (per km^2)	Source of data (World Population Prospects, UN, 2004 edition updated as on dates indicated)
World (land area excludes Antarctica)	134.94 million km^2	52	July 16, 2012
Bangladesh	147,570 km^2	964	2011
Taiwan	35,980 km^2	639	June 30, 2009
South Korea	99,538 km^2	487	2009
India	3.29 million km^2	368	March 1, 2011
Japan	377,873 km^2	337	September 1, 2010
Vietnam	331,689 km^2	259	April 1, 2009
UK	243,610 km^2	255	January 1, 2010
Germany	357,022 km^2	229	January 1, 2010
Italy	301,318 km^2	200	June 2009
China	9.64 million km^2	140	June 16, 2012
Poland	312,685 km^2	122	January 1, 2010
Indonesia	1.90 million km^2	121	2010
France	551,500 km^2	114	January 1, 2010
Spain	506,030 km^2	91	January 1, 2010
Burkina Faso	274,000 km^2	58	2009
Mexico	1.96 million km^2	57	—
Tanzania	945,087 km^2	46	2009
South Africa	1.22 million km^2	41	July 1, 2011
Colombia	1.14 km^2	41	July 16, 2012
United States	9.83 million km^2	32	July 16, 2012
Peru	1.39 million km^2	29	October 23, 2011
Brazil	8.51 million km^2	23	July 16, 2012
Chile	756,096 km^2	23	July 16, 2012
Russia	17.10 million km^2	8.3	—
Canada	9.98 million km^2	3.5	January 20, 2012
Australia	7.68 million km^2	3	July 16, 2012

The countries, which have low population density and large areas, enjoy considerable flexibility in apportioning their land for different land uses including human settlements and industries although they may not be endowed with much mineral resources as is the case of Japan, Taiwan, South Korea etc. However, the problems are the most acute in cases of the countries which have high population densities and are also rich in mineral resources. Since mineral resources are totally location-specific and have to be mined where they are, conflict with other land uses may very often arise—especially human settlements that predate the mines. The choice is either to displace the settlements or not to mine at all. Both the options are real hard.

2.2.5 Industries

The increase in population after the industrial revolution supported by increased volumes of international trade in the later part of the eighteenth century has increased the demand for the manufactured products and hence an increase in not only towns but also industries. The industrial products may be mineral-based or agro-based (including horticulture- and forest-based). But the latter also need some minerals or mineral-based products for processing of the raw materials. Therefore, industrialization led to proliferation of the mining industries also.

Theoretically, industries are location-independent and should have unlimited flexibility of land. But, there are eleven factors which influence the choice of the location of an industry. These factors are as follows:

(a) Nearness to source of raw materials (mines, farms, orchards, forests etc.)
(b) Continuous supply of water to support both the industrial processes and the employees and their families
(c) Scale of production and favourable benefit/cost ratio which requires not only adequate but also contiguous land (a large steel plant may require 6–10 km^2 of land)
(d) Electric transmission line
(e) Roads and railways for transportation of both raw materials and products
(f) Nearness to ports in case of import of raw materials and/or export of products
(g) Additional land for building residential colonies for the employees
(h) Nearness to consuming centres for the products
(i) Nearness to villages and towns for the purpose of availability of labour and social infrastructure (schools, hospitals, places of worship, market etc.) for the employees
(j) Favourable policies of the local government
(k) Congenial political atmosphere in the area

Fulfilment of all these 11 conditions means that the location of an industry gets automatically fixed, flexibility being very limited. In case of mining industry, there is, of course, no choice of location and either the conditions have to be made favourable or the mine would not start.

However, some of these conditions are required to be fulfilled for certain other land uses like agriculture, forestry etc. And that gives an additional dimension to the competition. There is also competition not only for land but also for water, infrastructure etc.

2.2.6 Real Estate

The meaning of real estate is not limited to some residential property constructed on a piece of land or an agricultural land. It is the land with which some vested and business interest is associated. It may be a vacant land presently without any economic activity but with investment and value-addition potentialities ranging from residential to highway and infrastructure projects. Real estate sector plays an important role in the economy of practically all countries. In India, this estate sector is the largest employer after agriculture and is expected to grow at 30 % rate (Dhake 2013).

2.2.7 Environment

Strictly speaking, environment is not a land-based tangible entity. That makes it difficult to reliably quantify it and evaluate it in terms of money. It means the totality of surrounding conditions and it deals not just with physical living, but it also entails emotional values as may be derived from soothing landscapes, historical and pre-historical ruins, man-made modern structures of aesthetic appeal, and folk traditions. Environment includes both visible and invisible as also living and non-living things which influence people's bodies and minds. It manifests in the form of some measurable physical entities as follows:

(a) Area of open space free from buildings and industries
(b) Amounts of impurities in solid and liquid anthropogenic wastes
(c) Degree of purity of air
(d) Degree of purity of ground water
(e) Canopy coverage of forests
(f) Number and type of wildlife, insect and plant species in different habitats like forests, wetlands, deserts and oceans
(g) Area covered by wetland
(h) Degree of purity of ocean water
(i) Volumes of ice/snow in Antarctica, Arctic, Greenland and mountain peaks
(j) Intensity of noise generated anthropogenically in specific areas
(k) Intensity of artificial light
(l) Freedom from any disruption of the socio-cultural values in human settlements

The ultimate effect of all these elements of environment is on human health directly or indirectly. In the UN Conference on Sustainable Development (Rio+20) held in June, 2012, poverty alleviation implying economic development and health improvement have been recognized as important pointers towards environmental sustainability. Besides, excess concentration of CO_2, methane, nitrogen oxides (NO_x), sulphur oxides (SO_x) and water vapour in air known as the greenhouse gases are responsible for the global warming and climate change.

In India, the Central Pollution Control Board (CPCB) under the Ministry of Environment and Forest (MoEF) has issued on January 13, 2010, a framework termed Comprehensive Environmental Pollution Index (CEPI) by combining three factors concerning environmental pollution in an industrialized area as follows:

(a) Pollutant: This factor has been categorized into groups and subgroups having scores depending on presence/absence of toxins and their nature (whether carcinogenic or not) and also scale of industrial activity.
(b) Pathway: It relates to (i) ambient concentration of pollutants and has been categorized into low, moderate, high and critical having increasing marks; (ii) mere evidence of adverse impact on people, (iii) definite proof of adverse impact on people; and (iv) degree of adversity of the affection.
(c) Receptor: It relates to (i) number of people affected within 2 km distance; (ii) level of exposure; and (iii) additional risk to sensitive receptors like sensitive people, historical/archaeological monuments, places of worship, sanctuary, national parks and ecological habitat.
(d) Additional high risk element: It pertains to (i) inadequacy or adequacy of pollution-control measures; (ii) inadequacy or adequacy of design of the pollution control facilities; (iii) whether the facilities are operational or not; and (iv) whether the facilities are maintained or not.

Aggregate CEPI scores are computed based on the above factors on a scale ranging up to 100. It has been suggested in the framework that CEPI scores of 70 and above should be considered as critically polluted industrial areas whereas CEPI between 60 and 70 should be considered as severely polluted area. As per this framework, some industrial areas including mining areas have been declared as critically polluted.

2.3 Land-Use Management

In countries like India, large population combined with high population density calls for delicate balancing insofar as allocation of land for different uses is concerned. But, in India there is no land-use policy. In the absence of definite policy direction on land-use, differences between executive and judiciary are frequent. Even from the National Land Acquisition and Rehabilitation & Resettlement (LARR) Bill in proposal stage as in July 2013, some sectors like mining (not other industries), railways, roadways etc. have been left out and land acquisition for these projects will remain under the purview of separate laws.

The first step for effective land-use management is delineation of the boundaries of different natural resources and then earmarking of the balance area for other anthropogenic uses. Natural resources like forest, wildlife, biodiversity, wetlands and deserts have evolved naturally through hundreds of millions of years. Human settlements have also evolved through hundreds of years on their own. Today they are seen as occupying certain definite areas on the land. These lands, thus, stand delineated naturally. A land-use policy should therefore appear simply to involve allocation and demarcation of the balance areas in a country for agricultural and industrial activities. But, in practice, it is not at all simple particularly in the cases of the two invisible entities namely the overground environment and the underground mineral resources.

Environment, of course, is the common denominator of all anthropogenic activities namely agriculture, human settlements, mining and other industries and some of its elements like air, ocean and ice are independent of any political boundary. The other elements are of course country-specific and land-use management policy of a country must factor them. The environmentally fragile zones can also be mapped and delineated. But the process is both time- and money-consuming, and only very few countries have actually undertaken it, not to speak of completing. In India, detailed environmental study is actually done only when an industry or a new township is to be established and it is not, therefore, possible to know in advance where it will be possible to set up a new industry or a new township.

It is, however, the mineral resources which, although independent of the political boundaries, are considered as a country's endowment. But, being underground, without exploration (especially drilling) and feasibility study it is not possible to delineate a definite boundary of land as mineral-bearing. But, a mineral resource is also a dynamic entity; its minability at any point of time depends on technologies of mining, processing and utilization at that point of time. At some other future time, all these may change and so may the boundaries of the mineral resource. Moreover, exploration involves long gestation as well as monetary investment without any return and without any certainty of success. So, it is practically impossible to know on which part of the land of a country, new townships or new industries or any other overground human activity can be permitted without the possibility of any future conflict with mining.

Generally, different land-uses are governed by different laws administered by different authorities, in India as well as in other countries. The multiplicity of laws complicates the problems of land-use management all the more. In India, the acts (along with the rules under them) directly or indirectly influencing feasibility and economics of exploration and mining of minerals are as follows:

1. Mines and Minerals (Development & Regulation) or MMDR Act [New revised version under consideration of Parliament as in July, 2013]
2. Atomic Energy Act (stipulates that if during exploration any of the atomic minerals like those containing uranium and thorium, beryllium, lithium, tantalum, zirconium and niobium is encountered, it has to be reported to the Atomic Energy Commission who will regulate the activities)

3. Coal (Conservation & Development) Act (applicable for conservation and development of coal)
4. Coal-bearing Areas (Acquisition & Development) Act
5. Oilfield (Regulation & Development) Act
6. Offshore Area Mineral (Development & Regulation) Act
7. Forest Rights Act, 2006 (comes into relevance when mineral deposits occur in forest areas; conditions like compensatory afforestation charge for diversion of forest land to non-forest activities like mining apply).
8. Environment Protection Act, 1986 (protection of heritage structures, flora and fauna; prevention and control of air, water and noise pollution; restoration of land; rehabilitation of project affected people (PAP); Coastal Management Zone or CMZ regulation).
9. The Ancient Monuments & Archaeological Sites & Remains Act, 1958 (Mining is prohibited in areas where ancient monuments are present).
10. Scheduled Tribes & Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 (it recognizes the traditional rights of people living and using the forest; it recognizes both individual and community rights and stipulates that these rights should first be settled before acquisition of land for a mining project including exploration activities).
11. Land Acquisition and Rehabilitation & Resettlement Act [under consideration of Parliament to replace the Land Acquisition Act; it concerns acquisition of land other than certain land-uses including roadways, railways and mining]
12. Companies Act
13. Water Pollution (Prevention & Control) Act
14. Air Pollution (Prevention & Control) Act
15. Wildlife Protection Act
16. National Biological Diversity Act
17. Groundwater Act (it obliges all wanting electricity connection for pumping ground water to obtain prior permit from the Groundwater Authority).
18. Panchayati Raj (Extension to the Scheduled Areas) Act, 1996 (Prior recommendation of Gram Sabha (village council) is mandatory before granting of prospecting licence or mining lease in Scheduled areas)
19. The Coal India (Regulation of Transfer & Validation) Act, 2000 (It empowers Central Government to direct the transfer of land or of rights in or over land in relation to a coal mine or coke oven plant vested in Coal India Limited which is a public sector company under Government of India; it also obliges any authority not to use a coal-bearing land for greenfield or brownfield town planning, industry etc. without prior approval of the Ministry of Coal, Government of India)

The fourth and the last two deal with land-use issues only in a limited manner and none of the laws has anything to fully and comprehensively address the conflicts amongst the different land-uses although in the Forest Policy, mineral exploitation has been made permissible in certain classes of forest. But mining in those classes of forest is at a heavy cost which include not only the NPV but also the cost of afforestation of twice the number of trees cut, in a non-forest area.

In some countries, coal mining, oil exploitation, other minerals mining and environment including air and water pollution are clubbed under a single law administered by a single authority. In South Africa, there is a plan to integrate mining and preservation of biodiversity under a single administrative authority.

Ground water is vital and critical natural commodity. It is required in every sector of economy—agriculture, industry, human settlement etc. According to the laws of various countries groundwater is a mineral just as oil and gas are. Some of the characteristics of ground water (e.g., invisibility and depth) are similar to those of a typical mineral resource. But there is no law to regulate the exploitation of this precious natural commodity in India or other countries (the Groundwater Act of India seeks to regulate only the electricity connection for pumps). However, drilling a borehole or digging a well for exploitation of ground water requires negligible land and does not clash with the land-uses other than mining. But, in case of mining, the quarry or shaft may pierce through groundwater table and the unregulated outflow of ground water is mostly wasted or grossly misused resulting in drought-like situation in the vicinity of the mines. The South African Government is planning to introduce a system of water licensing while granting lease for mining. But till 2012, there was nothing like that on ground.

Overall, a comprehensive land-use policy and management will not be practically possible because of insufficient knowledge of the hidden mineral resources and also the dynamics of minability and usability of the known resources.

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Chapter 3
Relationship Between Minerals and Human

Relationship between minerals and humans dates back to the era when the humans were still primitive, much before they became “modern” about 120,000 years ago. But the relationship then was not centred on conscious knowledge or effort. Conscious relationship probably started with the invention of artificial fire made with the help of flint about 30,000 years ago. Since then, from that single mineral, usage by the humans has diversified to scores of minerals and metals which are indispensable for humans. Moreover, harnessing of the mineral resources has also graduated from primitive practice of picking up minerals strewn on the surface to organized mining from the depths under the land and even seabed.

Economic development of a nation and a country comes from agricultural and industrial production as well as from services rendered by the humans all of which are measurable in terms of money. But ultimately, the intangible services either end up in or are associated with some tangible agricultural or industrial product. And all productions are essentially the result of interaction between humans and one or the other mineral which comes through mining. Although a section of the humans takes part in the production of minerals, all humans are actually consumers of minerals either directly or indirectly.

3.1 Humans as Consumers of Minerals

Although the human population has all along been steadily increasing, the industrial revolution during the second half of the eighteenth century and the population explosion in course of the next 200 years (population jumped from 813 million in 1800 AD to about seven billion in 2010 AD and projected to be 9.3 billion by 2050 AD) have had a multiplying effect on mineral consumption which, in turn, resulted in proliferation of mines all over the world. Annexure I and II bring out the extent to which the humans are dependent on minerals.

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Energy is the prime-mover of all human activities—industrial and agricultural. Total dependence on human energy for movement on land and also rivers by rowing rafts gave way to animal energy when horses were domesticated around 50,000 years ago. Long after that, about 4000 BC, wheel and carts were invented. Alongside, sometime after 8000 BC, when linen was made out of some plant fibres, sailing boats aided by wind energy were a big leap forward in sea transportation and international trade. But the industrial revolution in the second half of the eighteenth century followed by trade with the help of coal-fired steam ships, changed the scenario altogether. Huge volumes of international trade necessarily triggered industrial activity. Coal replaced charcoal in various metallurgical processes to convert minerals to metals needed to manufacture machinery and various industrial products much in demand by the people. Population explosion that followed, multiplied this demand and hence, industrial activity. Later on, appearance of petroleum in human life in a big way after 1859 followed much later by natural gas gave further boost to this development. Meanwhile transmission of electricity for practical use became a reality. Energy from uranium started being harnessed from the 1950s. Today, the linchpin of energy is electric power and that of transportation is petroleum. And as regards power, coal dominates the scenario supplemented by other non-renewable sources of energy (e.g. natural gas, uranium) and renewable energy sources (e.g. hydroelectricity, solar energy, wind energy etc.). As regards, uranium, its contribution is far less in comparison to coal in the global context. There are only a few countries in the total power generation of which uranium accounts for a substantial share. France has only recently become dependent on nuclear energy after its last coal mine was exhausted in 2004; Canada and Germany are also phasing out their nuclear power plants. The extent to which different countries depend on coal for fulfilment of power demand, can be gauged from Table 3.1.

In 2006, coal accounted for over 39 % of the world's electricity and its growth till 2030 has been projected by the International Energy Outlook to be at the rate of 1.5 %.

Overall, the rate of energy growth exceeded that of population growth between the period 1990 and 2008 as shown in Table 3.2.

The above growth is notwithstanding the fact that 1.46 billion or about 24 % of the people in the world did not have any access to electricity (IEA 2009). The corresponding figures for India and sub-Saharan Africa are 400 million (35 % of the population; mostly rural) and 90 % of the rural population respectively.

Table 3.1 Share of coal in power generation

Poland:	94.8 %	South Africa:	93.0 %	India:	66.0 %
Australia:	76.9 %	Israel:	77 %	China:	76.2 %
Kazakhstan:	70 %	Czech Republic:	66.7 %	Morocco:	68 %
Greece:	62.3 %	Germany:	52.0 %	USA:	49.9 %
Denmark:	47.3 %	UK:	32.9 %	EU countries:	27.2 %

Source: IEA (2005, 2006)

Table 3.2 Growth of population and energy usage (per capita and total) in different regions/countries during 1990–2008

Country	Per capita energy use (non-renewable and renewable) (kWh/capita)			Population (million)			Total energy use (non-renewable and renewable) (1,000 TWh)		
	1990	2008	Growth (%)	1990	2008	Growth (%)	1990	2008	Growth (%)
World	19,422	21,283	10	5,265	6,688	27	102.3	142.3	39
USA	89,021	87,216	−2	250	305	22	22.3	26.6	20
EU (27 countries)	40,240	40,821	1	473	499	5	19.0	20.4	7
Middle East	19,422	34,774	79	132	199	51	2.6	6.9	170
China	8,839	18,609	111	1,141	1,333	17	10.1	24.8	146
Latin America	11,281	14,421	28	355	462	30	4.0	6.7	66
Africa	7,094	7,792	10	634	984	55	4.5	7.7	70
India	4,419	6,280	42	850	1,140	34	3.8	7.2	91
Others (remaining countries of Asia and Oceania)	19,422	21,283	10	5,265	6,688	27	102.3	142.3	39

Source: IEA and World Bank (downloaded through www.google.com)

As regards only the non-renewable energy sources, coal is at present and will remain, at least till 2030, the linchpin of power generation in the world. The International Energy Outlook 2004 projects that its use is expected to increase in all regions with the exception of Europe and the CIS countries outside Russia. Till 2030, the share of coal in the primary energy supply will continue to be at the present level of 80–81 %. And power is the motive force behind both industrial and agricultural growth. Table 3.3 shows how coal production has grown vis-à-vis the population in the world and in the two countries namely US (the largest economy) and India (developing economy).

Table 3.3 shows that while the overall coal consumption in the world during the last century has increased steadily in sync with the population, the former has always been ahead of the latter. Same is the situation in India where coal has the most dominant role in power generation. The situation in US, however, is somewhat different. Till 1950, coal was ahead of population in growth rate, but thereafter it has registered negative or low rate. The reason is that after 1950, other sources of energy like nuclear, hydro, coal mine and coal bed methane, natural gas and, in recent years, shale gas have pitched in so much so that today the contribution of coal in total power generation has fallen below 50 % (Table 3.1). In India, however, the phenomenal growth has always been sustained due to double effect of abundance of coal resource and dearth of resources of the other non-renewable energy minerals. Only of late, due to environmental constraints, India's dependence on imported coal has been rising but still, indigenous production is far more than import.

Table 3.3 Growth of population and coal consumption in world, US and India

Year	World				US				India			
	Population		Coal consumption		Population		Coal consumption		Population		Coal consumption	
	Number (million)	Annualized growth rate (%)	Quantity (million tonnes)	Annualized growth rate (%)	Number (million)	Annualized growth rate (%)	Quantity (million tonnes)	Annualized growth rate (%)	Number (million)	Annualized growth rate (%)	Quantity (million tonnes)	Annualized growth rate (%)
1900	1,650	–	780	–	76.21	–	0.20	–	271.31	–	6.22	–
1910	1,750	0.61	–	–	92.23	2.10	0.32	6.00	260.28	−0.41	12.97	10.85
1920	1,860	0.63	1,200	2.69	106.02	1.38	1.07	23.44	249.70	−0.41	18.25	4.07
1930	2,070	0.11	–	–	123.20	1.72	1.80	6.82	277.18	1.00	24.18	3.25
1940	2,300	0.11	1,700	2.08	132.16	0.73	1.75	−0.28	316.00	1.40	29.86	2.35
1950	2,556	0.11	–	–	151.33	1.45	2.75	5.71	350.45	1.09	31.90	0.68
1960	3,039	0.19	2,100	1.18	179.32	1.85	2.20	−2.00	431.46	2.31	51.27	6.07
1970	3,707	0.22	–	–	203.30	1.34	2.42	1.00	539.08	2.49	71.24	3.90
1980	4,454	0.20	3,444	3.20	226.54	1.14	2.18	−0.99	688.96	2.78	109.32	5.35
1990	5,279	0.19	4,558	3.23	248.71	0.98	0.54	−7.52	833.93	2.10	214.99	9.67
2000	6,083	0.15	4,440	−0.25	281.42	1.32	0.73	3.52	1,014.00	2.16	350.04	6.28
2010	6,849	0.13	7,244	6.30	308.75	0.97	0.54	2.60	1,170.01	1.54	648.28	8.52
2030	8,247 (projected)	1.02 (projected)	9,417 (projected)	1.50	–	–	–	–	–	–	–	–

Source: (1) US Census Bureau; (2) United Nations, 1999, The World at Six Billion, World Population from Year 0 to Stabilization; (3) US Census Bureau, 2008, The Mid-year Population for the World: 1950–2050; (4) Registrar of Census, Government of India; (5) Matos, G.R. and Wagner, L.A., 1998, Consumption of materials in the United States, 1900–1995, Annual Review of Energy and the Environment, v. 23; (6) US Energy Information Administration, 1982–2010; (7) Annual Energy Review, 1980–2010, US; (8) USBM & USGS, Mineral Year Book, US; (9) Central Statistical Organisation, Government of India, Energy Statistics, 2011; (10) Ministry of Mines, Government of India, Annual Report, 2010–2011; (11) Indian Bureau of Mines, Growth of Indian Mineral Industry (1947–1991), February, 1992; (12) Chatterjee, K.K., 2006, Uses of Energy Minerals and Changing Techniques, New Age International, New Delhi; (13) Coggin Brown, J. and Dey, A.K., 1955, Oxford University Press

Notes

1. Coal includes lignite
2. For the world, consumption is assumed to be equal to production, because the imports and exports cancel each other and the stocks and inventories, for which reliable data are not available, are mostly short term and hence ignored
3. The data for US pertain to apparent consumption
4. For India, the data for the years 1970 onwards pertain to the period April to March of the following year
5. For India, data pertain to apparent consumption [production + import – export – stock (up to the year 2000 only)]; prior to 1950, both import and export were negligible and then up to 1980, import was negligible
6. Prior to 1950, the data pertaining to India include those to Pakistan and Myanmar

As regards the two non-renewable energy minerals namely oil and gas which have become the backbone of economy in practically all the countries including those with abundant coal availability, the trends in their growth in the world, US and India are shown in Table 3.4.

Oil is indispensible for transportation and natural gas is mainly utilized in thermal power and fertilizer industries. In the latter two industries coal also plays a significant role as has been discussed earlier. Table 3.4 shows that growth in these industries has been far outstripping the growth in population. In other words, the mobility and agricultural activity of the humans have been ever increasing at a fast pace.

Besides the energy minerals, an essential ingredient of fertilizers is phosphate minerals. There are three vital plant nutrients namely nitrogen, potassium and phosphorus. Nitrogen is commonly provided to the plants through urea, organic manure etc. Till the nineteenth century, Chile saltpetre was the only mineral providing nitrogen to the plants. But in the early twentieth century, synthetic fertilizer manufacturing process was developed and, by the 1940s, use of this mineral for fertilizer manufacturing petered out. Of the other two nutrients, phosphate is by far more common in chemical fertilizers which account for 80–85 % of its use and its consumption is the key indicator of fertilizer consumption and agricultural activity.

The most important indicator of construction activities is the consumption of cement and steel and that of communication infrastructure is copper consumption. The principal mineral raw material for steel manufacturing is iron ore and that for cement manufacturing is limestone.

The world consumptions of phosphate, steel, iron ore, cement and copper vis-á-vis the population growth are shown in Table 3.5.

Consumption of fertilizer (hence that of phosphate) is influenced by the following factors:

(a) Village-centric market and hence sensitivity to politics particularly in the democratic countries
(b) Dispersed nature of demand
(c) Level of crop yields
(d) Degree of variability in crop yields (different crops require different types and doses of fertilizer)
(e) Lack of knowledge among the rural people of many poor countries about the fertilizer and their benefits
(f) General apathy of the illiterate or semiliterate rural farmers to go against traditions
(g) Availability of the right fertilizer at the right time
(h) Price of fertilizer relative to crop prices (invariably higher price making the benefit-cost ratio unfavourable calling for subsidization by the governments)
(i) Efficiency or inefficiency of making the benefits of government subsidies to reach the small farmers which constitute the overwhelming majority in the developing countries
(j) Environmental lobbies in some developed countries against use of chemical fertilizers

Table 3.4 Growth of population and oil and gas consumption in world, US and India

Year	World			United States			India				
		Consumption of petroleum products			Consumption of oil & gas products			Crude petroleum consumption		Natural gas utilized	
	Annualized population growth rate (%)	Rate of consumption (million barrels per day)	Annualized growth rate (%)	Annualized population growth rate (%)	Total (million tonnes)	Annualized growth rate (%)	Annualized population growth rate (%)	Total (million tonnes except where mentioned as 'million litres')	Annualized growth rate (%)	Total (billion m^3)	Annualized growth rate (%)
1900	–	–	–	–	1.29	–	–	3.42 million litres	–	–	–
1910	0.61	–	–	2.10	1.81	4.03	–0.41	16.00 million litres	36.78	–	–
1920	0.63	–	–	1.38	2.37	3.09	–0.41	50.37 million litres	21.48	–	–
1930	0.11	–	–	1.72	3.59	5.15	1.00	220.77 million litres	33.56	–	–
1940	0.11	–	–	0.73	4.54	2.65	1.40	300.00 million litres	3.59	–	–
1950	0.11	–	–	1.45	10.21	12.49	1.09	0.30	–	0.15	–
1960	0.19	–	–	1.85	23.12	12.64	2.31	6.20	196.67	0.68	35.33
1970	0.22	–	–	1.34	49.40	11.37	2.49	18.51	19.85	0.65	–0.44
1980	0.20	63.10	–	1.14	87.26	7.66	2.78	26.76	4.46	1.52	13.38
1990	0.19	66.51	0.54	0.98	85.25	–0.23	2.10	53.72	10.07	12.77	74.01
2000	0.15	76.78	1.54	1.32	108.54	2.73	2.16	106.52	9.83	27.86	11.82
2010	0.13	83.71 (2009)	1.00	0.97	93.89	–1.35	1.54	192.95	81.14	47.25	6.96

(continued)

Table 3.4 (continued)

Source: (1) US Census Bureau; (2) United Nations, 1999, The World at Six Billion, World Population from Year 0 to Stabilization; (3) US Census Bureau, 2008, The Mid-year Population for the World: 1950–2050; (4) Registrar of Census, Government of India; (5) Matos G R & Wagner L A, 1998, Consumption of materials in the United States, 1900–1995, Annual Review of Energy and the Environment, v. 23; (6) US Energy Information Administration, 1982–2010; (7) Annual Energy Review, 1980–2010, US; (8) USBM & USGS, Mineral Year Book, US; (9) Central Statistical Organisation, Government of India, Energy Statistics, 2011; (10) Ministry of Mines, Government of India, Annual Report, 2010–2011; (11) Indian Bureau of Mines, Growth of Indian Mineral Industry (1947–1991), February, 1992; (12) Chatterjee, K.K., 2006, Uses of Energy Minerals and Changing Techniques, New Age International, New Delhi; (13) Coggin Brown, J. and Dey, A.K., 1955, Oxford University Press

Notes

1. For the world, consumption has been calculated from the figures of consumption in India and India's share in the world consumption both sourced to Titi Tudorancea Bulletin, Global edition, 21.10.2010
2. The data for US pertain to apparent consumption
3. For India, the data for the years 1970 onwards pertain to the period April to March of the following year
4. For India, data pertain to apparent consumption [production + import − export]; for crude petroleum, export was practically nil; and for natural gas both import and export were practically nil
5. Prior to 1950, the data pertaining to India include those to Pakistan and Myanmar
6. Data for natural gas pertain to the gas utilized after excluding that flared and re-injected into reservoirs for secondary production

Table 3.5 Growth of population and consumption of steel, iron ore, cement, copper and phosphate in the world

Year	Annualized population growth rate in world (%)	World consumption									
		Steel		Iron ore		Cement		Copper		Phosphate	
		Total (million tonnes)	Annualized growth rate (%)	Total (million tonnes)	Annualized growth rate (%)	Total (million tonnes)	Annualized growth rate (%)	Total (million tonnes)	Annualized growth rate (%)	Total (million tonnes)	Annualized growth rate (%)
1900	–	28.30	–	–	–	–	–	0.50	–	–	–
1910	0.61	60.30	11.31	–	–	–	–	0.86	7.20	–	–
1920	0.63	72.50	2.02	–	–	–	–	0.96	1.16	–	–
1930	0.11	95.10	2.38	–	–	62.10	–	1.61	6.77	–	–
1940	0.11	140.60	4.78	–	–	81.00	3.04	2.13 (1939)	3.59	–	–
1950	0.11	191.60	3.63	–	–	133.00	6.42	–	–	–	–
1960	0.19	346.40	8.08	–	–	–	–	5.90	8.43	43.00 (1961)	–
1970	0.22	595.40	7.19	780.51 (1971)	–	–	–	7.59	2.69	81.10	9.84
1980	0.20	717.40	2.05	931.34	2.15	–	–	9.26	2.20	142.90	7.62
1990	0.19	770.46	0.74	984.45	0.57	–	–	10.80	1.66	160.60	1.24
2000	0.15	848.93	1.02	1,050.65	0.67	1,600.00	22.06	14.99	3.88	146.40	–0.88
2010	0.13	1,417.26	6.69	2,349.65	12.36	3,310.00	10.69	15.90	0.60	178.50	2.19

Source: (1) International Iron & Steel Association, Brussels, Steel Statistical Yearbook, 1978–2011; (2) USGS, Mineral Commodities Summary, 2000, 2001, 2012; (3) USGS, Cement Statistics, 2010; (4) USGS, 2010, Copper Statistics (1900–1939); (5) International Copper Study Group, 2010, World Copper Fact Book (1950–2000); (6) International Fertilizer Industries Association, Paris, 2011, Global Phosphate Production—Trends from 1961 to 2000

Notes

1. World consumption is assumed to be equal to production, because the imports and exports cancel each other and the stocks and inventories, for which reliable data are not available, are mostly short term and hence ignored
2. The disproportionately high figure for iron ore compared to steel in 2010 is due to the fact that the accumulated stocks of the ore in Chinese ports and also of the ore fines in Indian mines were large

Due to one or more of the above reasons, the consumption of fertilizers (and hence phosphate) has been erratic particularly in the poor countries of Africa and Asia which may be the cause of the negative growth in the consumption of phosphate during the decade 1990–2000 (more precisely 1988–1994).

The above tables decisively indicate that the pace of industrialization (including that in the agricultural sector) has been much faster than that of the population increase in the US, in India and in the world as a whole since the beginning of the twentieth century exerting ever-increasing pressure on the Earth's finite non-renewable mineral resources. In other words, post-industrial revolution, the pace of rise in average per capita consumption of minerals is too fast. And this scenario is notwithstanding the fact that demand is generally more than consumption if we go by the common concept of demand being the capacity to consume. For example, production of coal in India during the 1-year period April, 2011-March, 2012 was 533 million tonnes (Ministry of Mines, Government of India, Annual Report, 2011–2012). Since this was short of the need of the consuming industries (mainly thermal power, iron & steel and cement), a quantity of 98.9 million tonnes was imported during the same year (*London Commodity News,* May 8, 2012). Export being negligible save some small quantities exported to Bangladesh, Nepal and Bhutan, the apparent consumption during that year was about 631 million tonnes. Even this was substantially short of the projected demand of 696 million tonnes for 2011–2012. And this gap of 65 million tonnes between demand and consumption would have widened many times if we consider that 35 % or 400 million people were yet to gain any access to electricity and the needs of a vast majority of Indian homes and industries are only partially fulfilled (e.g., in the state of Manipur, there is hardly 2–3 h of power supply daily as in 2012–2013). Shortfall in domestic production in an individual country can be made up through import from another country, but shortfall in the world cannot be.

3.2 Humans as Producers of Minerals

It is apparent from the foregoing that demand management alone is not the answer and austerity cannot be forced on a selected section of the people. There is need also to address the issues concerning production or supply. However, the mineral resources being finite as well as location-specific, there is the danger of overexploitation. Many easy-to-mine near-surface mineral deposits have already exhausted, limiting the option to go for difficult and deep-seated deposits located off-shore and perhaps (in the foreseeable future) in asteroids and planets making mining and minerals costly. Since the population and industrialization are growing relentlessly and a life without minerals and industries is ruled out, sustainability of mineral resources i.e. raw material security has now become the primary concern in most, if not all, of the countries worldwide. The challenge is to keep producing minerals till the distant future and beyond. The answer lies in not only extending the life indices of the available mineral resources but also opening newer and newer frontiers of technology for fulfilling the needs for minerals. All these issues are discussed as follows.

3.2.1 Dynamics of Reserves/Resources

Mineral resources being located underground remain invisible to humans and it is never possible to estimate with cent per cent accuracy the quantity and quality of the resources at the exploration stage before mining. The technologies of exploration, mining and recovery also keep changing with research, development and innovation bringing to light new resources and altering the parameters of minability, utilization and economics. Such factors bring in an element of dynamics to the quantities of economically minable reserves of different minerals. The factors can be specified as follows:

(a) *Exploration:* This may or may not lead to discovery of new reserves depending on the success ratio, which varies from mineral to mineral. For example, success ratio for simple deposits like those of coal is high but for petroleum, it can be as low as 10 %. It also depends on whether the area is already well-explored or virgin. Furthermore, it will depend on the minable depth which in turn will depend on the long-term market price of the mineral. For example, a low-priced mineral like limestone or aggregate cannot be economically mined beyond a shallow depth and consequently, discovery of deep-seated deposits of such minerals will not lead to addition of any minable reserve. On the other hand, high-priced minerals like gold, diamond, copper etc. can be explored to great depths. And if exploration is successful, it will result in augmentation of the reserves.

(b) *Cut-off grade:* This is the minimum economic grade above which minerals are mined from a deposit. Since this has an economic connotation, it is both mineral- and time-dependent. In other words, with time the economic parameters like price, costs of technologies for mining and recovering etc. keep changing. The reserves of a particular mineral at a particular point of time are estimated above its cut-off grade at that point of time and the resources estimated below it. So, when cut-off grade is brought down due to favourable changes in the economic parameters, portion of the resource will become reserves and the latter will increase.

(c) *Cut-off thickness:* This applies to bedded deposits subjected to mining by mechanized method (e.g. coal, sylvite) and is the minimum thickness at which the cutting machine can cut the mineral bed without mixing up with the waste rocks of the hanging or foot walls. Obviously it depends on the design parameters of the machine available in the market at a particular point of time and is, therefore, a matter of business decision by the investor. Quantities in the mineral beds which are thinner than the cut off limit will be resource and in those which are thicker will be reserve. If and when new machines are manufactured with new design parameters, the cut-off thickness may change and so may the minable reserves.

(d) *System of classification:* Historically, different countries had been following different systems of classification of the total geological resources according to their level of geological exploration and techno-economic feasibility. Broad categories generally used were 'resource' and 'reserve', the former estimated with relatively low level of exploration and not conceived to be minable in the near-future while the latter with relatively more intensive exploration and also tested to be minable. But the definitions of the reserve and resource and the subcategories under each varied from one system to another. Only in the beginning of this century, the United Nations Economic Cooperation for Europe (UNECE) has brought about the United Nations Framework Classification (UNFC) system which has been adopted by many countries including India as the standard classification system. Of course some developed countries like Australia, US, UK, Canada, Russia etc. still follow their respective classification systems (JORC, SME, IMMM etc.) their definitions are by and large similar to those of UNFC system. Now, when we examine the archival data on reserve of different minerals they might be on the basis of different systems and definitions. This may be a reason for any apparent change of the reserve figure vis-a-vis the resource and the change may be drastic as happened in India in 2000 to the inventories of the metallic and industrial minerals (Table 3.7).

(e) *Depletion:* Reserves in the mines have been under exploitation continuously resulting in their decrease or depletion. This, obviously, has a negative effect on the available reserve.

(f) *Degree of reliability of the primary source of data:* When we compare reserve figures of a country or of the world reported at different times, the agency responsible for estimation or compilation of the data may make a difference to their reliability. The reliability depends on the following factors:

   (i) Coverage of the data/survey
   (ii) Method of estimation of the resources and reserves
   (iii) Method of sampling and compilation
   (iv) System of classification of resources followed

   It may not be possible that the same agency's data will always be available especially in case of archival data.

(g) *Governmental policy:* Governments' policies may indirectly affect the national inventories of reserves and resources. Such inventories are necessary for macroeconomic policy planning like land-use planning, prioritization of infrastructure development, export-import policy formulation, prioritization of regional exploration programmes etc. The impact of governments' policies on reserve dynamism in the national scale is discussed as follows:

   (i) Policies may encourage or discourage regional exploration. In 2003, in South Africa the mineral rights were unshackled from the exclusive control of the whites and opened up; this liberalization policy had a dramatic effect on the investment on mineral exploration which jumped up by over

46 % compared to 2002. In India, a private company is allowed to mine coal only if it utilizes its entire produce in a captive plant (power, steel, cement) or sell the surplus coal to the Coal India Limited (a public sector company under the Government of India) at a price determined by the Government; this restrictive policy has hindered investment in coal sector.

(ii) Government may make it mandatory to adopt certain cut-off grade depending on the international practice and also in the interest of conservation of resources or in some other national interest. A recent example from India can be cited. In July, 2012, The Government of India has announced that the cut-off grade for hematite reserves would be reduced from 55 % Fe to 45 % Fe. This implies that the ore in the range 45–55 % Fe, which was being rejected and dumped as waste, can no longer be treated thus and will have to be treated as useful and stacked separately for proper utilization. They may be used for blending with higher grade ore (as China is doing) or beneficiated and upgraded. In both cases it will serve the cause of conservation of iron ore resources. An obvious fallout of this policy announcement is that a substantial portion of the hitherto resource will move to reserve category and the country's iron ore reserve inventory will go up substantially in one jump enabling the Government to liberalize export. Incidentally, industries are currently doing R & D to work out the usability of the banded hematite quartzite (BHQ) which has a still lower grade ranging from 35 to 45 % Fe; and if successful and if the Government follows up by making it mandatory to categorize it under reserve, the reserve of iron ore will be further augmented.

(iii) Government may mandate a particular resource classification system to be followed by all agencies in a country. In India, it was at the Government's behest that the Geological Survey of India system was introduced in 1982 and again the UNFC system in 2002.

(iv) Export-import policy may serve to alter the reserve-resource ratio in the national inventory. In India, in most of the iron ore mining areas, the mode of occurrence of the ore is such that for every tonne of lump 2–3 tonnes of fines are produced which do not have any use in the indigenous iron and steel plants due to lack of enough agglomeration facilities. Consequently, a substantial portion of the *unwanted* fines locked up in the deposits are considered as resource although a portion of the fines produced (unintentionally along with the lumps) is exported. In 2012, the Government of India abolished the export duty on iron ore pellets (made from fines) while increasing the export duty on fines as such. This is expected to facilitate large scale investment for setting up pelletization plants to convert the fines to pellets and then export. In due course, the resource of the fines will move up to reserve category.

(v) Laws for preservation of environment and for conservation of forest may severely restrict mining in otherwise economic deposits and thus the reserves can be relegated to resource category.

Table 3.6 Dynamics of estimated reserves of oil, natural gas and coal in world

Year	Quantities of estimate		
	Oil (Proved reserve in billion barrels)	Natural gas (Proved reserve in trillion cubic metres)	Coal (Recoverable reserve in billion tonnes)
1960	302.00	–	4,209.99
1970	611.40	–	–
1975	–	72.05	536.35 (1974)
1980	648.50	72.84	661.41
1985	–	96.31	–
1990	1,001.00	112.93	1,038.74
2000	1,017	145.70	987.94
2010	1,349	187.10	861.00

Source: (1) Energy Statistics, Department of Energy, US Government (for the oil reserves); (2) US Department of Energy, Energy Information Administration (for natural gas reserves up to 2000); (3) British Petroleum, June, 2011, Statistical Review of World Energy (for natural gas reserves for 2010); (4) US Department of Interior, Geological Survey, A progress Report, January 1, 1960 (for estimate of coal reserve for 1960); (5) Coal Reserves & Resources, Gentle Cough, 2007 (unofficial estimate of coal reserve for 1974); (6) World Coal Study, 1980 (for estimate of coal reserve for 1980); (7) Energy Information Administration, USA, 2012, Security of World Coal Reserves (for coal reserve of 1990); (8) Colorado River Commission of Nevada, 2002, World Fossil Fuel Reserves and Depletion (for estimate of coal reserve for 2000); (9) World Energy Council (for estimate of coal reserve for 2010)
Note: All units have been converted to metric system

All these factors positively or negatively impact the reserve of a mineral through the years and net balance of its increase/decrease in respect of the world reserves of the key energy minerals is demonstrated in Table 3.6.

The high coal reserve in 1960 was estimated without any consideration of the cut-off thickness; it may not indicate its recoverability and by today's standards, may not be categorized as reserve. From 1975 onwards, the reserves are on the basis of cut-off thickness of 0.6 m (Table 3.6).

Table 3.7 demonstrates the dynamism of reserves through the past in respect of the key minerals for energy, industry and agriculture.

It can be seen from Tables 3.3, 3.4, 3.5, 3.6, and 3.7 that the increasing consumption, and hence production, of minerals has little effect on the long-term increase/decrease of the balance reserves as far as most of the key minerals are concerned. However, coal is an exceptional case. Overall world reserves have shown declining trend since 1990 although in India it has been registering a reverse trend. The reasons are:

(i) In the developed countries, virgin areas for discovering new deposits have become scarce.
(ii) In those countries, since the 1990s, environmental activists advocating clean coal have become increasingly more vocal restricting the minable reserves further.

Table 3.7 Dynamics of estimated reserves of chromite, coal, iron ore, petroleum, natural gas, manganese ore and phosphate in India (*Production in million tonnes*)

Year	Coal		Petroleum		Natural gas		Iron ore		Chromite		Manganese ore		Phosphorite	
	Production	Reserve (billion tonnes)	Production	Reserve (million tonnes)	Production	Reserve (billion m^3)	Production	Reserve (billion tonnes)	Production	Reserve (million tonnes)	Production	Reserve (million tonnes)	Production	Reserve (million tonnes)
1960	53	6 (600 m)	0.5	49	N.A.	21	16.6	1	0.1	5	1.5	183	Nil	Nil
1970	74	94 (0.45 m, 600 m)	6.8	130	N.A.	66	31.4	10	0.3	14	1.7	108	0.2	57
1975	96	81 (1.2 m, 600 m)	8.7	125 (1974)	N.A.	68 (1974)	41.8	13	0.5	17	1.6	80	0.5	65
1980	109	86 (1.2 m, 600 m) (1978)	9.4	366	N.A.	352	41.9	18	0.3	111	1.7	117	0.5	130
1985	150	158 (0.5 m, 1,200 m)	29.9	500	N.A.	479	44.1	13	0.6	139	1.3	154	0.9	115
1990	202	170 (0.5 m, 1,200 m) (1988)	33.3	638 (1988)	N.A.	579 (1988)	54.6	13	1.0	88	1.4	176	0.7	115
1995	273	197 (0.9 m, 1,200 m) (1994)	34.9	779 (1996)	N.A.	640 (1996)	66.6	13	1.7	86	1.8	167	1.4	145
2000	314	212 (0.9 m, 1,200 m)	32.4	645	N.A.	647	80.8	9	2.0	47	1.6	105	1.4	75
2005	407	253 (0.9 m, 1,200 m) (2006)	32,2	786	N.A.	1,101	165.2	7	3.7	66	1.4	132	2.1	53
2010	537	277 (0.9 m, 1,200 m)	38.0	775	N.A.	1,149	212.6	8	3.9	54	2.9	142	1.7	35

(continued)

Table 3.7 (continued)

Source: (1) Indian Bureau of Mines, Indian Mineral Year Book, 1960–2007 (for reserve data up to 2006; (2) Indian Bureau of Mines, Growth of Indian Mineral Industry (1947–1991), February, 1992 (for production data from 1960 to 1990); (3) Indian Bureau of Mines, Indian Mineral Year Book, 1997–2008 (for production data from 1995 to 2005); (4) Ministry of Mines, Government of India, Annual Report, 2012 (for reserve data pertaining to 2010 in respect of all minerals other than coal, petroleum and natural gas); (5) Ministry of Petroleum & Natural Gas, Statistics, 2010–2011 (for reserve data of petroleum and natural gas for 2005 and 2010)

Notes

1. The figures are rounded off
2. All reserve figures till 1995 (minerals other than coal, petroleum and natural gas) are in situ geological reserve categorized as per old Indian system
3. Reserves (minerals other than coal, petroleum and natural gas) as in 2000 onwards are as per UNFC system
4. For the reserves of coal, cut-off thickness and depth of estimation are shown within parentheses
5. Wherever the year of estimation is different from the year indicated in column, the same is indicated within parenthesis
6. As regards coal, petroleum and natural gas the classification system followed is not UNFC
7. The reserves of natural gas as in 2005 and 2010 include coal bed methane
8. The production from 1995 onwards pertain to April-March, the following year
9. "N.A." means "Not available"
10. As regards production of natural gas, the published data pertain to "utilized" natural gas which is the same as consumption (see Table 3.4) and the data for production, which should be more than that for consumption, are not available

(iii) In India, the above factor has still not become a formidable obstacle against mining of coal.
(iv) Besides, the restricting geological factors like seam thickness, depth etc. are more and more coming to light in the yet-to-be mined deposits in some of the developed countries.
(v) The rate of growth in coal production and consumption in the fastest developing and biggest producing country China has been very high during the recent years.

3.2.2 Technology of Exploration and Mining

From four-hundredth century BC to the twenty-first century AD, the techniques of exploration and mining have been an open-ended advancement. The earliest evidence of mining based on some dolerite hammers and picks, which have been dated to 42,000 years ago, consisted in shallow open cast pits to dig out hematite and yellow ochre in Swaziland. And today, application of sophisticated metals and information & communication technology (ICT) are being talked about for opening newer and newer frontiers of mining.

External geo-political circumstances are now directing the attention of policy makers to assess the feasibility of exploiting mineral resources which are located under such difficult geo-environmental conditions and depths that a few years ago they would have been out of scope of mining operations. The exploitation of these resources will require paradigm shift to the use of robotics in mining and the integration of ICT into all phases of minerals extraction. At the same time mineral extraction is an expanding large-scale activity in many of the lower and middle-income countries of the world with an urgent need for safer and more environmentally sound operations. These boundary conditions will define new ways for the integration of ICT for future mining operations. Focus will be on fully automated deep underground operations of strategic minerals coupled with in-situ mineral processing and on safer ways of mineral extraction.

Since around 1960, there has been a revolution in the field of various *new* materials of the kinds of electronic chips, highly special glass and advanced ceramic products, the metal-matrix composites, special alloys and super-alloys, semi-conductors, laser, radar, super-conductors, components of space ships, materials for artificial human organs, nanotubes, materials required for geoengineering and environmental hazard mitigation, wind turbine components etc. and the researches in material science are currently going in this direction. Mineral commodities like graphite, fullerene, helium, zeolite, quartz, micro-diamonds and metals like rare earth metals will play increasing role in development of such materials and they will call for not only shifting of focus but also development of new methods of exploration and mining.

One of the most powerful forces influencing the economic importance of mineral raw materials needed by the humankind in the future is technological change. In many cases, their rapid diffusion can drastically increase the demand for new metals

Table 3.8 Global demand for selected metals in emerging technologies during 2006 and 2030 related to their total production during 2006

Raw material	Production 2006 (tonnes)	Demand from emerging technologies		Demand/2006-production ratio	
		2006 (tonnes)	2030 (tonnes)	2006	2030
Gallium	152	28	603	0.18	3.97
Indium	581	234	1,911	0.40	3.29
Germanium	100	28	220	0.28	2.20
Neodymium (rare earth)	16.8	4.0	27.9	0.23	1.66
Platinum	255	Negligible	345	—	1.35
Tantalum	1,384	551	1,410	0.40	1.02
Silver	19,051	5,342	15,823	0.28	0.83
Cobalt	62,270	12,820	26,860	0.21	0.43
Palladium	267	23	77	0.09	0.29
Copper	15,093,000	1,410,000	3,696,070	0.09	0.24

Source: European Commission (2010) (through web site)

and minerals. A study commissioned by the German Federal Ministry of Economics & Technology in 2010 has indicated that the emerging technologies have created new demand for certain not-so-widely used metals and this trend is expected to continue very rapidly till 2030 as shown in Table 3.8.

So, current technological research, development and innovation for management of the material needs of the humankind with the help of the known and as-yet-unknown natural resources are progressing in the directions of development of novel technologies and new ICT-based processing sequences involving minimally invasive technologies (endoscopic mining), 4-D modelling, virtual reality applications, detection and mapping of mineral occurrences at greater depths or in difficult formations followed up with computer tomography of drill-core sample together with remote, real-time processing of borehole data (e-exploration). The aim is the development of the 'Measuring While Drilling' (MWD) concepts and of the sampling and sensing techniques in order to increase the cost-efficiency and flexibility of exploration sampling operations. The targets for exploration and mining through application of all these technologies are as under:

(a) Depths beyond 4,000 m (the current maximum depth of mining of minerals other than oil and gas) at minimum cost to the environment and other land-uses: Technologies are still (2012) in conceptual stage and yet to be fully developed for practical trials. However, the Swedish conceptual study "Smart Mine of the Future" delivered its results in November 2010. Among other issues, the study stated the need for fully automated continuous mechanical excavation, no human presence in the production area, pre-concentration and resource characterization. The emerging concepts centre on new deep-penetrating geophysical technologies, near-zero impact surface operations requiring better management of waste streams, advanced reclamation techniques, self contained extraction and processing systems and also advanced ICT (Abrahamson et al. 2009) for ensuring security of personnel.

(b) Oceans: As of now (2012) the oceans are mostly unexplored. But whatever is known they are the storehouse of abundant resources of a host of metals, the reserves of which are scarce onshore. They include titanium, platinum, manganese, copper, cobalt, nickel etc. needed by the manufacturers of electronic goods, lithium car batteries, solar panels, wind turbines, flat screen television, compact fluorescent light bulbs, missile guidance systems etc.; and also methane (or gas) hydrate. Some of the technologies developed or under development are as follows.

  (i) Robotics, computer mapping and underwater drilling for mining nodules rich in manganese, nickel, cobalt and copper from about three miles below the water surface between Hawaii and Mexico;
  (ii) Ship or floating platform fitted with a nearly mile-long hose to vacuum up fine silt suspended near bottom of the Red Sea;
  (iii) Submersible vehicles to plough seabed and send mineral-rich slurry into pipes for processing on the surface;
  (iv) Ships capable of mining at depths up to 7,000 m aided by high-speed data processing supercomputers with petaflop capability through a cluster approach connected by a fibre optic switch which will enable modelling and simulation of high-speed nuclear process including radiation modelling (China has the capability of mining at 7,000 m depth and some other countries (e.g., US, Russia, Japan, India etc.) at depths ranging from 5,000 to 6,000 m); and
  (v) An instrument called 'ChemCam' for chemical analysis of rocks from a remote location (it uses laser-induced breakdown spectroscopy; the energy from the laser excites atoms in a rock into an ionized, glowing plasma and the ChemCam catches the light from the spark with a remotely located telescope and analyses it with the help of spectrometers for information about what elements are in the target rock).

Some of these technologies have not yet been tested in field. Nevertheless they indicate the direction of the current thought process of the scientists.

(c) Extra-terrestrial bodies like asteroids, Moon, Mars etc.: Fairly sufficient knowledge of mineral resources has been deciphered from the data gathered through satellite reconnaissance and the analyses of (1) the samples collected by remote-controlled sample-collectors and (2) in situ samples with the help of instruments like ChemCam (see above).

The Moon contains recoverable elements that include silicon, iron, aluminium, magnesium, calcium, hydrogen, deuterium, tritium, helium-3 and also ilmenite—all entrapped in a thick layer of regolith. In the Martian regolith, while all these elements are present, additionally copper, sulphur and phosphorus are also available. Interest in asteroid mining arose because of the high metal content—up to 91 % Fe, 8.5 % Ni and 0.6 % Co and also platinum, iridium, osmium and palladium; and the water contained in the asteroids can be extracted and used for production of liquid oxygen (LOX).

But currently it is the crypto-cometary bodies called Near-Earth-Objects (NEOs) which are receiving relatively more attention on account of the Low-Earth-Orbit (LEO) projects like establishment of International Space Station, orbital hotels, geo-stationary solar power generators etc. and the high cost of delivering large payloads from the Earth to the LEO. The resources in the regolith of the NEOs that are currently being targeted are (1) propulsive fuel, (2) consumables for life support and (3) structural materials. Besides, their cores are believed to be made up of iron and nickel.

The technological challenges of exploration and mining in the Moon, the Mars, the asteroids and the NEOs are as follows:

(i) Remote sensing techniques of exploration pose no problem.
(ii) As regards drilling, special technologies for countering low gravity as well as special coring devices (e.g., rock-melting and laser beam device) are under R & D.
(iii) For extracting the huge resource of helium-3 from the regolith, the latter will be required to be heated to 8,000 °C.
(iv) The challenges in NEOs are their small diameters ranging (from 6 m to 38.5 km) and negligible magnetic fields. Hence the mining equipment would be exposed to the solar wind and would need radiation-hardened electronics.
(v) Mining in regolith, hard rock and cometary ices—each requires a different approach.
(vi) The rapid rotation and asymmetric mass distribution of the asteroids and companion moons will produce variable gravitational forces making approach and landing difficult.
(vii) Another problem being addressed is development of highly efficient, easily deployable, flexible photovoltaic cells for constructing solar power arrays to meet the power requirements for mining.

From an economical perspective the development of deposits that are not economically viable in 2012 may become an attractive resource within the near future. In short term, the development of advanced robotics for underground and surface operations along with tele-mining for mining under extreme geo-environmental conditions like those under the sea appears to be well within the horizon. Tele-analysis of rocks using the instrument ChemCam is currently underway by the Mars rover CURIOSITY.

3.3 Singularity of Ultimate Human Capability

As civilization advanced, humankind moved away from non-mineral to non-renewable minerals. Animal bones and logs of wood gave way to rocks and metals for weapon-making; horses gave way to horse-driven wheeled carts, steam-powered carriages and motorized vehicles for movement on land; logs of wood gave way to boats and mechanized ships for crossing the waters; wood gave way to charcoal,

coal, oil, gas and uranium for sourcing energy and finally, even if we, as scientists are predicting, move more towards inexhaustible sources of energy like solar, wind, hydrogen, nuclear fusion (using deuterium, tritium and helium-3), we will need more minerals and technology to harness them.

According to an estimation made in 2002, an American consumed 23 tonnes of mineral raw material per year, a citizen of European Union about 15 tonnes and an average Indian about 0.75 tonnes and there will be a quantum jump in these figures in the medium term. Economists expected that the level of total mineral production which was in the region of 30 billion tonnes in 2002 would double in 2030. And the challenge is to exploit all minerals and metals needed by humankind at affordable cost, at minimal strain to the environment of the Earth and in a socially compatible manner. The answer to this challenge lies in technology and human resource development.

As regards technology, continuous endeavours are underway for development and innovation in the fields of deep mining, ocean exploration and mining and exploitation of extra-terrestrial resources. And technology is advancing at a very fast pace. So much so that it is indeed difficult to envision the point which the advancement of technology will ultimately take us to. The term 'singularity' has been in use by mathematicians and physicists to convey the breaking down of the predictive ability of physics at the primordial point of time when the density of the universe and the curvature of space-time would have been infinite. Ray Kurzweil, in his Law of Accelerating Return, which was propounded in 2011, has used the term "technological singularity" to conceive a postulated time in the future when social, scientific, technological and economic changes will be so fast that we cannot even imagine what will happen from our present perspective.

And the question arises: are our new generation scientists, geologists and mining engineers being prepared by the universities and the institutes for this challenge?

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Chapter 4
Minerals and Energy—Non-renewable Sources

4.1 Conventional Sources

The non-renewable sources of energy, as known in April, 2013 can be grouped as:

1. Conventional (traditionally established)
   - Coal
   - Petroleum
   - Natural gas
   - Uranium
2. Unconventional (recent)
   - Methane [Coal bed methane (CBM); Coal mine methane (CMM); Abandoned mine methane (AMM); Ventilation air methane (VAM)]
   - Thorium
   - Oil shale
   - Shale gas
   - Tight gas

   These are discussed as follows.

4.1.1 Coal

Coal is the oldest energy mineral used by the humans in general and industries in particular. Like everything else, coal has both positive and negative points. The positive points include:

1. Coal is abundant and widespread. Its resources occur in over 70 countries and it is produced in over 50 countries. They comprise major developed and

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developing countries like US, China, India, Russia, Australia, South Africa, Germany, Ukraine and Indonesia.
2. Due to its geological nature of occurrence, cost of its exploration and mining is the lowest amongst the energy minerals.
3. Due to well-spread production centres and low cost, coal is subjected to free competition worldwide and consequently, its price remains affordable.
4. Coal is readily available from a wide variety of sources in a well-supplied worldwide market.
5. Being a solid mineral, it is easy to transport to demand centres by rail and ship quickly, safely and easily and also store it in bulk in open yards.
6. Besides thermal value, it is also a source of a wide variety of chemicals.
7. It is widely used in an array of industries from brick to electricity as well as in millions of rural homes.
8. The technologies of harnessing its thermal and chemical values are well-established.
9. It is the most used mineral in thermal power industries and is a critical raw material in iron and cement industries–all infrastructure industries vital for economic growth.
10. Coal is not dependent on weather or rainfall unlike many of the unconventional kinds of energy like hydro, solar and wind energy.

On the other hand, the environmentalists regard coal as the enemy of humanity due to the fact that it is the most carbon-intensive fuel and is one of the most potential pollutants. The negative points are:

1. Particulate emissions such as ash resulting from coal combustion.
2. Emission of harmful trace elements like mercury, selenium and arsenic.
3. Oxides of nitrogen collectively referred to as NO_x which are formed from the combustion process where air is used and/or where nitrogen is present in the coal and which can contribute to smog, ground level ozone, acid rain and greenhouse gas emissions.
4. Oxides of sulphur collectively referred to as SO_x which are formed from the combustion of the sulphur contained in many coals and which can cause acid rain.
5. Waste material consisting primarily of mineral matter with small amounts of unburnt carbon posing problems of disposal.
6. Generation of CO_2 from burning of coal which accounts for over 40 % of global warming (besides coal, other sources like firewood also contribute to the total CO_2 to the extent of 15–20 %).
7. Large land requirement: A coal-based power plant usually requires an area of 36.32 ha for generation of every megawatt-hour of electricity.
8. Freshwater requirement: A coal-based power plant may require over 1000 l of freshwater for generation of every megawatt-hour of electricity.

The disadvantages notwithstanding, coal continues and will continue to play a unique role in meeting the demand for energy in most of the countries for both power generation and industrial applications without raising geopolitical safety issues. Indigenous coal resources enable socioeconomic development of a large number of countries and can guard against import dependence and price shocks. The economic and social benefits can be summarized as follows.

1. Coal can be transported to demand centres quickly, safely and easily by rail, road or ship.
2. Coal produces 39 % of the world's electricity and around 70 % of the world's steel (IEA 2002; WCI 2003).
3. Coal used in power generation is projected to grow 60 % by 2030 (IEA 2002).
4. The benefits amount to a gain of billions of dollars to the developed and developing countries alike.
5. Over one billion people have gained access to electricity via coal since the early 1980s (China has achieved almost 100 % electrification–over 84 % coal-based–and the highest GDP growth rate in the world).
6. Coal provides over seven million jobs worldwide and coal production is key economic activity in many communities (WCI 2002).
7. Coal has provided people with dependable and affordable access to modern energy, particularly electricity which has, in turn, served to improve public health, enable access to modern information and education services and save people from subsistence tasks such as gathering fuel thus allowing them to pursue other more rewarding activities.

As regards the concerns of greenhouse gas and global warming, extensive and intensive researches are underway for developing technology pathways. In fact, technologies are already known, but the scientists and technologists are trying to answer the question of how to reduce the cost of making coal environment-friendly. The technologies include:

4.1.1.1 Clean Coal Technology (CCT)

These technologies are a range of technological options which improve the environmental performance of coal. They reduce emissions, reduce waste and increase the amount of energy gained from each tonne of coal. The environmental benefits and the technology options for achieving them are discussed as follows.

(i) *Reduction of particulate emissions*: Emissions of particulates such as ash, which impact local visibility and affect people's respiratory systems, are the more visible side-effects of coal combustion. The common technologies in vogue are the different coal washing/beneficiation processes and electro-static precipitators (ESP) and fabric filters (or bag-houses). The former is for reducing ash before combustion (generally at or near the mine-head) and thus improving the efficiency of power plants which leads to reduction of emissions. In the ESP, particulates are removed by over 99.5 % from the flue gases emitted during combustion of coal.

(ii) *Reduction of trace element emissions*: ESP and fabric filters (described above) and fluidized combustion and desulphurization equipment (described in the next paragraph) can significantly reduce trace element emissions. In addition, activated carbon injection technique is especially suitable for this purpose. It involves activated carbon being injected into the flue gas stream exiting the boiler and absorbing the trace element pollutants onto the particulate matter, which is then removed in the particulate control equipment (ESP etc.).

(iii) *Prevention of acid rain and smog*: Acid rain came to global attention during the latter part of the twentieth century when acidification of lakes and damage of trees in parts of Europe and North America were discovered. The reasons have been traced to the emission of oxides of sulphur (SO_X) and of nitrogen (NO_X) during combustion of coal which react chemically with water vapour and other substances in the atmosphere to form acids and are deposited in rainfall. NO_X can also contribute to the development of smog. The technology option for removal of SO_X is the flue gas desulphurization (FGD or scrubber) process for use in coal-fired power stations. By this technology up to 99 % of SO_X can be removed. The technology options for removal of NO_X are the selective catalytic and non-catalytic reductions (SCR and SCNR) which can remove NO_X by 80–90 % post-combustion. Fluidized bed combustion (FBC) is a high-efficiency advanced technological approach to reducing both NO_X and SO_X emissions. FBC has achieved reduction of over 90 %.

(iv) *Reducing CO_2 emission*: CO_2 emission can be reduced by improving the thermal efficiency (i.e. fuel conversion efficiency) of coal-fired power stations. The global average thermal efficiency of coal-fired powered stations was around 30 %; but in new super-critical plants operating at higher steam temperature and pressure than conventional plants, this has improved to 43–45 %.

Near zero emission of CO_2 has been achieved through carbon capture and sequestration (CCS). This technology allows emissions of CO_2 to be stripped out of the exhaust stream of coal combustion and deposited in such a way that they do not enter the atmosphere. As regards storage of the captured CO_2, the preferred option presently is underground–in natural geological structures, in depleted oil and gas wells, in deep saline aquifers and in coal seams which are not mineable. The captured CO_2 can also be used economically for food processing, fish farming etc.

However CCS technologies face challenges like huge investment and land requirements. Moreover, maintaining a CCS system requires a lot of energy thus delivering less net energy per unit of coal.

An alternative approach is to produce a gas from coal in integrated gasification combined cycle (IGCC) systems. In this, coal is not combusted directly but reacted with oxygen and steam to produce what is called ‘syngas’ composed mainly of hydrogen and carbon monoxide (CO). This syngas is cleaned of impurities and then burnt in a gas turbine to generate electricity and to produce steam for a steam power cycle. The efficiency level of IGCC systems is high–50 % or even more. They also remove 95–99 % of the NO_X and SO_X emissions.

According to data compiled by the World Coal Institute (WCI 2005), the levels of CO_2 reduction by different technology options are: up to 5 % by coal upgradation, up to 22 % by efficiency improvements of existing plants, up to 25 % by advanced technologies and up to 99 % by CCS technology.

4.1.1.2 Coal Liquefaction to Convert It to Gasoline and Diesel

Germany first produced coal-derived liquid fuels during the World War II followed later on by South Africa which is now the leading producer. China is also experiencing growth in coal liquefaction as a way of utilizing the country's enormous reserves of coal. As in 2012, India is yet to make a beginning in this area. There are two key methods of liquefaction:

(i) Direct coal liquefaction through a single process
(ii) Indirect coal liquefaction where coal is first gasified and then converted to liquid

The commercial scale coal liquefaction process currently in operation worldwide is the indirect Sasol (Fischer-Tropsch) process. The liquefied coal can be refined to produce transport fuels and other oil products, in a way acting as a substitute of crude oil.

The IEA has in 2004 made a forecast about indispensability of coal in everyday life in 2030. A comparative scenario between 2002 and 2030 are shown in Table 4.1.

It can be surmised that the trend is towards more and more coal-based thermal power generation capacity at the cost of all other applications mainly due to increase in the electrification rates in the developing countries from 66 % in 2002 to 78 % in 2030 thanks to the affordable cost of coal. However, subsequent to 2004, environmental lobbies against coal mining have become more and more vocal. One of their arguments is that the costs of the externalities are never factored in determination of the cost of coal. The externalities comprise the damages to environment and climate caused by the emissions from coal-fired power plants; and if all the mitigation measures are implemented, the cost will no longer be low. In other words, it is fallacious to consider only the present monetary cost of coal leaving out the costs of the externalities which encourage its uninhibited use. Exact cost implications of the externalities in monetary terms have not yet been standardized; but according to the estimation of the WWF International (Ina Pozon 2006), the indicative externality impact on cost per kWh of power in Europe could be 3.5–4.0 times of the current apparent cost. According to data compiled by Justin Mundy (2006), the incremental

Table 4.1 Comparative coal usage in 2002 and 2030

Coal usage	2002 (%)	2030 (%)
Power generation	69	79
Industry	16	12
Residential	3	1
Other	12	8

Table 4.2 Comparison among China and EU regarding CO_2 emission in 2002 and 2030

CO_2 emissions (million tonnes/year)	2002	2030	Change
World – total	23,579	38,214	14,635 (62.1 %)
World – coal	9,023	13,866	4,843 (53.7 %)
China – total	3,307	7,144	3,837 (116.0 %)
China – coal	2,621	5,194	2,573 (98.2 %)
EU – total	3,731	4,488	757 (20.3 %)
EU – coal	1,170	1,091	–79 (–6.8 %)
Coal-fired power plant capacity (gigawatts)			
World	1,135	2,156	1,021 (90.0 %)
China	247	776	529 (214.2 %)
EU	111	87	–24 (–21.6 %)

cost of clean coal was hypothesized to be in the range Euro 200–600/kWh. The range itself is wide; besides there was and is still no real market, hence this hypothesis has not yet been tested and it is not possible to know the actual cost. Nevertheless, the cost of clean coal will be significantly higher than raw coal. This will imply that coal will, no doubt, lose its principal forte of being affordable to the common people of the developing countries. It is, therefore, necessary that the R&D efforts on carbon capture and sequestration (CCS) technology be made business-oriented and market-friendly. Achieving this will require scaling up of the R&D and increasing the number of commercial scale storage pilot projects ensuring that the general public is consulted throughout.

According to data compiled by Justin Mundy (2006), China will play an important role as far as CO_2 emissions–especially due to coal-fired power generation–is concerned till at least 2030 (Table 4.2).

Different governments are responding differently to the problem of CO_2 and particulate emissions and also global warming associated with coal. The governmental response is manifest in the form of both incentives and disincentives–mainly fiscal and legislative–as follows.

1. Carbon credit: A system of tradable carbon credit is now well established. These credits are generally represented as a GHG reduction equivalent to a tonne of carbon dioxide or carbon or methane. They are issued in the form of "Certificates of Emission Reduction" (CER) by the United Nations Framework Convention for Climate Change (UNFCCC) on the basis of verification certificate (Verified Emission Reduction or VER) by an authority designated by the UNFCCC for each country. A plant able to achieve reduction in GHG emission will earn 'credits', which it can sell to a plant emitting excess GHG. The bench mark for measuring reductions and excesses could be the targets set in Kyoto Protocol (1997) to which many countries are signatories. The credit can be earned through what is called Clean Development Mechanism (CDM) which can be implemented in the following two ways:

(i) By reducing emission of pollutants from the coal used, through clean coal technology (CCT), and
(ii) By reducing emission of pollutants from coal by partially substituting unclean coal by some clean energy.

London has become an important centre for carbon market. But demand and trade volume of CER is highly sensitive to economic growth because high economic growth means high consumption of energy and high rate of emission of CO_2.

2. India's energy saving certificates: In India, the National Action Plan on Climate Change has been announced in 2008. This plan mandates setting up of energy bench marks for each sector and allows trade in energy saving certificates in the domestic market. Those who surpass their targets will be given energy certificates which can be sold in an open market; they can also set off the extra savings for future adjustments when the targets are revised. The plan (in combination with the Energy Conservation Act, 2001) is intended to move the industries towards a cleaner route at the least cost to the industry and the economy.
3. Emission tax: In Russia, a system of imposing Emission Tax has been introduced to discourage use of CO_2-emitting technologies.
4. Climate change levy (CCL): In UK, the "green energy" producers are encouraged by exempting them from this levy which they would otherwise be required to pay.
5. Tax credit: This provision is available to environmentally beneficial projects in US.
6. Subsidy: A policy of subsidizing "green energy" introduced in Germany in 2000 has enabled many CCT projects commercially viable there.
7. Mix of tax and state funding: In China, the policy is to levy tax on sale of carbon credits and then to use the fund so collected for raising awareness of climate change and cutting emissions.
8. India's steam coal, which is used for power generation, contains high ash up to 50 % causing problems of disposal of bottom and fly ash and particulate emission. The Government of India, in 2001, has made it mandatory for the power stations located 1,000 km or more away from the supply source and for those located in urban, sensitive or critically polluted areas (irrespective of the distance) to use washed coal that has an ash content of not more than 34 %.
9. Carbon tax: Australia, in 2012, imposed carbon tax at a flat rate of A$ 23 per tonne of CO_2 emitted. The rate may change in future. This is in addition to the 30 % Minerals Resource Rent Tax on profits earned from coal mining which has nothing to do with pollution.

However, the current trend indicates that the role of coal as a source of electricity is becoming all the more important irrespective of the effectivity of technological, fiscal and legislative responses despite temporary set-backs on account of economic slowdown.

4.1.2 Petroleum

Chemically, crude oil refers to the chain of hydrocarbons having composition C_3H_8 (propane), C_4H_{10} (butane) and onwards. The world has come a long way since the drilling of first oil well in US on August 27, 1859. As of 2011, the world has consumed around 1,100 billion barrels of crude oil since then; and the remaining proved reserves stood at around 1,000 billion barrels. As in 2012, the average per capita consumption of petroleum is 14 barrels/day in the developed countries, three barrels/day in the developing countries and 1.2 barrels/day in India. A number of products are derived from crude petroleum and each of them has carved a niche utility where it is indispensable. Table 4.3 illustrates the broad scenario in the world.

In all the regions the demand of practically all the products declined in 2011. This is consistent with the global economic recession, particularly in the US and Europe. However, in most of the end-uses the scope of superior substitution is limited. The scenario in India, which is dependent on import to the extent of 65–70 % of its demand, may be seen from Table 4.4.

It can be seen that although the overall growth in demand during the period 1970–2009 was positive for all the individual products, there were ups and downs within the period. The surge of demand of LPG (mixture of propane or C_3H_8 and butane or C_4H_{10}) which is a cooking fuel was due to the Government's policy to discourage use of firewood by the poor people and heavy subsidization. Naphtha is a feedstock for both power and fertilizer; but it is also relatively costlier than the other competing raw materials in India and hence it is seen that towards the end of the period its use dwindled significantly. The decrease in demand for motor gasoline

Table 4.3 Utilitywise oil demand in different regions of the world during 2010 and 2011 (*Million barrels/day*)

Year	LPG and ethane	Naphtha	Motor gasoline	Jet/kerosene	Gas oil/ diesel	Residual fuel oil	Others	Total
Americas (minus Chile)								
2010	2.9	0.35	10.64	1.67	4.97	0.96	2.54	24.12
2011	3.01	0.36	10.39	1.67	5.08	0.91	2.50	23.92
Europe								
2010	0.96	1.27	2.21	1.23	6.20	1.31	1.51	14.70
2011	0.96	1.17	2.11`	1.24	6.14	1.26	1.49	14.37
Asia-Oceania + Chile								
2010	0.86	1.71	1.63	0.90	1.69	0.79	0.51	8.10
2011	0.85	1.71	1.61	0.88	1.70	0.79	0.59	8.13
Organization for Economic Cooperation and Development (OECD countries)								
2010	4.81	3.33	14.47	3.81	12.87	3.07	4.56	46.91
2011	4.82	3.24	14.12	3.79	12.91	2.96	4.58	46.41

Source: IEA: Oil Market Report dated August 10, 2012
Note: The figures pertain to demand which may be different from actual consumption

Table 4.4 Utilitywise demand of petroleum in India (*Million tonnes*)

Year	LPG	Naphtha	Petrol or motor gasoline	Jet or ATF	Kerosene	Gas oil/diesel (HSD & LDO)	Fuel oils	Others	Total
1970	0.18	0.90	1.45	0.69	3.28	4.93	4.66	3.05	19.14
1975	0.34 (15 %)	1.84 (17 %)	1.28 (−2 %)	0.90 (5 %)	3.10 (−1 %)	7.48 (9 %)	5.78 (4 %)	2.97 (−0.4 %)	23.69 (4 %)
1980	0.41 (4 %)	2.33 (5 %)	1.52 (4 %)	1.13 (5 %)	4.23 (7 %)	11.47 (11 %)	7.47 (6 %)	3.72 (5 %)	32.28 (7 %)
1985	1.24 (40 %)	3.11 (7 %)	2.28 (10 %)	1.45 (6 %)	6.23 (9 %)	16.01 (8 %)	7.90 (1 %)	5.15 (8 %)	43.37 (7 %)
1990	2.42 (19 %)	3.45 (11 %)	3.55 (11 %)	1.68 (3 %)	8.42 (7 %)	22.65 (8 %)	8.99 (3 %)	6.61 (6 %)	57.77 (7 %)
1995	3.92 (24 %)	4.15 (4 %)	4.68 (6 %)	2.08 (5 %)	9.93 (4 %)	33.57 (10 %)	11.16 (5 %)	8.58 (6 %)	78.07 (7 %)
2000	7.02 (16 %)	11.67 (36 %)	6.61 (8 %)	2.25 (2 %)	11.13 (2 %)	39.36 (3 %)	12.65 (3 %)	16.11 (18 %)	106.8 (7 %)
2005	10.46 (10 %)	12.19 (1 %)	8.65 (6 %)	3.30 (9 %)	9.54 (−3 %)	41.07 (1 %)	12.83 (0.3 %)	24.36 (10 %)	122.4 (3 %)
2009	13.12 (6 %)	10.24 (−4 %)	12.82 (12 %)	4.63 (10 %)	9.30 (−0.6 %)	56.78 (10 %)	11.59 (−2.4 %)	31.32 (7 %)	149.8 (6 %)
Growth (40 years)	73 times	11 times	9 times	7 times	3 times	12 times	2.5 times	10 times	8 times

Source: Ministry of Statistics & Programme Implementation (Government of India): Energy Statistics, 2012

Notes

1. The figures pertain to demand which may be different from actual consumption
2. The years refer to the period April to March of the following year
3. LPG means liquefied petroleum gas
4. ATF means aviation turbine fuel
5. HSDO means high speed diesel oil
6. LDO means light diesel oil
7. Others include lubricants, bitumen, petroleum coke, refinery fuel etc

during the first half of the decade of 1970s was due to the ‘oil shock’; but later on, oil exploration was intensified in India leading to the discovery and development of the Bombay High and other offshore oilfields and the growth became consistent. ATF demand was throughout moderate but consistent because not only domestic aircrafts, but also foreign ones fill up their tanks in India. Kerosene ($C_{10}H_{22}$ to $C_{14}H_{30}$) is the poor people’s fuel and light in India and is heavily subsidized by the Government; but still it registered negative growth at times because of progress in rural electrification and encouragement by the Government for use of LPG also. HSD is used for running buses and trucks and LDO for tractors and industrial machines; and there has been a steady increase in the public road transport system as well as of deployment of tractors in agricultural farms. Fuel oil is used for initial firing of industrial furnaces and its growth was always low and even negative during industrial slowdown.

Technology-related aspects which play a key role in determining the competitive advantage/disadvantage of oil over other energy sources can be grouped as under:

1. Upstream exploration and exploitation: The progress in oil exploration during the last over 150 years has been phenomenal. From the ‘cable tool method’ deployed by Drake in 1859 for drilling the first oil well, technologies of remote sensing, geophysical surveys (gravity, magnetic, seismic and electric) and advanced drilling techniques during the second half of the 20th century are now being supplemented by 3-D and 4-D seismic imaging coupled with computer-enhanced processing, drilling engineering, wire-line imaging and advanced well-testing etc., which have opened up new vistas for exploration and development. Now, drilling for oil has reached depths beyond 11,200 m (Sakhalin Island at Russia’s far-east).
2. Transportation: Depending on the geographical locations and the distances from the oilfield to the refinery or the market centres, various modes of transport for crude oil are put to use as under:
   (i) By road in oil tankers
   (ii) By rail in tank wagons
   (iii) By sea in large (75,000–115,000 dwt capacity), very large crude carriers or VLCC (150,000–320,000 dwt capacity) and ultra large crude carriers or ULCC (320,000–550,000 dwt capacity)
   (iv) By pipelines for distances that may be as long as 3,200 km (Alberta to Toronto, Canada)

However, grave environmental damages are associated with oil spills which are not uncommon particularly during maritime transportation. The oil spill in the Gulf of Mexico on April 20, 2010 (60,000–96,000 tonnes) and in 1979 (1 million tonnes), in California in 2007 (220,000 tonnes), in Spain in 1992 (80,000 tonnes) etc. have illustrated the extent of damage possible to the aquatic environment (estimations ranged up to hundreds of billions of dollars). The adverse effects including those on aquatic life as well as on shorelines can last for tens of years and cleanup operations are also very costly. Presently, the technologies comprise:

(i) Mechanical: The equipments include a variety of brooms, skimmers and natural and synthetic sorbent materials which are used to capture and store the spilled oil until it can be disposed properly.
(ii) Chemical: These include dispersants and gelling agents for preventing oil from spreading.
(iii) Biological: Certain bacteria have the ability to consume oil.

Besides, during pipeline transportation, broken pipes can contaminate water supplies.

3. Refining: It includes fractional distillation and then refining. It is at the stage of fractional distillation that mixtures of different useful products are separated into light distillates (LPG, motor gasoline, naphtha etc.), middle distillates (kerosene, ATF, HSD and LDO), heavy ends (lubricants, petroleum coke etc.) and other special products (white oil, paraffin wax etc.), which are then refined. Refining involves chemical conversion by cracking (breaking down of molecules at high temperature generally in presence of a catalyst to obtain a new product).
4. Downstream non-fuel products: By cracking, aromatics and olefins are obtained which are subjected to further chemical processing. As a result of this processing various non-fuel industrial products like detergents, synthetic rubber etc. are obtained.

Sulphur in crude oil has an ambiguous role. Petroleum contains sulphur varying in amount up to 5 %. Sulphur-containing compounds get into oil during its formation itself. If its content is up to 0.45 %, the oil is called 'sweet oil' (e.g., Brent crude of Texas). If it is recovered as by-product it adds to the economic value of the oil; but if it remains in the petroleum products, it is objectionable. And the sulphur along with carbon dioxide then adds to the vehicular pollution. As in 2009, it was estimated that the US enjoying the distinction of highest rate of car ownership (five cars for every six people) and one of the lowest fuel efficiency (its cars emitted much more carbon dioxide per year than all the cars in Japan, China, India, Russia, France, Italy, Germany, Britain and Canada put together). Improvement of fuel efficiency is one of the options being exercised by different countries including China and European Union which have set targets of vehicular emission for 2016–on an average 45 miles per gallon (mpg).

However, the problem of oil supply is extraordinary. It suffers from some exceptional barriers to additional production:

1. Production from existing major oilfields is declining sharply by two million barrels/day.
2. The most accessible oilfields have already been found and exploited.
3. Future discoveries lie in deep water and difficult geological structures miles underground (e.g. Arctic seabed).

4. Lack of equipment to drill in deep waters has delayed exploration by several countries.
5. Even production from established new discoveries has been delayed for want of deep-sea equipment.
6. Many countries are reluctant to expand drilling for oil even onshore because of environmental concerns (e.g., Saudi Arabia, US in Alaskan Wilderness Reserve).
7. Because of indispensability of oil, speculation and hoarding are tending to rise.
8. Because of its indispensability and concentration in a contiguous belt extending from the middle-east along the North Africa, it is the only mineral for which a cartel (Organization of Oil-Exporting Countries or OPEC) has been able to succeed and the international supply and price of oil are controlled by this cartel.
9. Success ratio of discovery of economic oil and gas fields is low (about 10 %).
10. There has been attempts to forecast the peak year of oil production by applying what is known as the 'King Hubert's Curve', according to which the production curve would continue to match the discovery curve with a lag of 30–40 years; but the forecasts have so far missed their marks.
11. Due to the campaign against vehicular emission, the refining standards have also become very stringent. Worldwide, the standard being followed is Euro-5 which has set limits on emissions of NO_x, total hydrocarbon (THC), non-methane hydrocarbon (NMHC), CO and particulate matter (PM) in terms of grammes/km. In 2014, the standards will be more stringent when Euro-6 comes into force.

As a result of all these factors, the response time of oil supply is the longest and there are far-reaching repercussions on oil price and on economy as a whole. Due to irresponsible speculation, oil prices sky-rocketed in 2008; as a result, consumers in US, who received loans from banks for acquiring real estates, had to utilize their resources for buying oil instead of servicing their bank loans; large scale defaults resulted in a chain of bank failures and economic recession.

Moreover, majority of the countries will continue to remain dependent on imported oil; and since the international oil market is linked to the US dollar (except Venezuelan oil which is linked to Euro), the higher and higher import bills will put greater and greater pressure on the US dollar which will make it vulnerable to weakening, making oil even costlier. Besides, oil has become such a security issue that natural calamities or even a mere possibility of a war in the oil-producing areas sends a panic wave across the world shooting up its price. Summing up, it may be surmised that, in the long run, availability of oil may not be an issue but its price will be.

4.1.3 Natural Gas

Natural gas is a mixture of methane (CH_4) and ethane (C_2H_6). It occurs either in association with and above petroleum or independently. But the geological nature of the trap is the same. Hence the exploration techniques are also same as those for petroleum. However all of the industrial uses of natural gas are not the same as those of petroleum.

Natural gas was once considered as an unwanted product (in India, till the 1960s) during oil recovery and used to be burnt out. This was because of the problems of the capital- and technology-intensive storage and transportation facilities. But now, the situation has changed completely and it has become a very important part of the energy stream–25 % of the world's energy profile and about 9 % of India's as in 2011. Exploration in and exploitation from independent natural gas reservoirs are now a regular practice. Tables 4.5 and 4.6 show a comparative picture in US and in India.

In US, natural gas has not been a high-growth fuel because there are other alternatives like coal, nuclear energy, coal mine methane and, more recently, shale gas. US being self-sufficient in energy minerals, growth in the industrial use of natural gas has been dependent there on its relative price advantage vis-à-vis the alternatives. As regards commercial and residential use, the supply in US is mainly through pipelines and this consumption has been excluded from the statistical report. Nevertheless, in 2011 power generation accounted for 34 % of the total gas consumption.

The scenario in India is however different. India is largely dependent on import for its non-renewable energy needs–whether coal or natural gas or nuclear fuel. Only recently a large reserve of natural gas has been discovered in Krishna-Godavari (KG) basin which is linked with captive power and fertilizer plants. This explains the spurt in growth in its use for power generation and fertilizer manufacturing after 2008 and as much as 45 % of the total consumption was accounted for by power generation while 28 % for fertilizer manufacture. But that spurt has been neutralized because:

(i) Production from that basin has declined (this trend has compelled the Government in 2012 to decide against setting up any gas-based power plant till 2015–2016).
(ii) Cost of recovery has increased.
(iii) Price fixed in the contract between the Government and the private company is under dispute.
(iv) Because of this dispute, other discovered reservoirs have not been developed.
(v) Import of natural gas is hampered by the problems of transportation and storage.
(vi) Import price of natural gas from the Gulf countries is linked to oil; as a result an increase in oil price automatically increases gas price thus creating problems in substituting oil by gas.

The problem of transportation and storage is, in fact, formidable. There are mainly two forms in which natural gas can be transported and/or stored as follows.

(a) Gaseous form: Natural gas can be transported either at normal pressure or in compressed form. When it is transported through pipelines for either domestic or industrial use, an elaborate network of pipelines has to be constructed–both on

Table 4.5 Consumption of natural gas in United States

Year	Commercial and residential		Industrial		Electric power generation		Vehicle fuel		Total	
	Quantity (billion m^3)	Growth over previous year (%)	Quantity (billion m^3)	Growth over previous year (%)	Quantity (billion m^3)	Growth over previous year (%)	Quantity (billion m^3)	Growth over previous year (%)	Quantity (billion m^3)	Growth over previous year (%)
2007	219.5	–	188.4	–	193.7	–	0.71	–	602.3	–
2008	227.8	3.78	188.8	0.21	188.8	–2.53	0.74	3.95	606.1	0.63
2009	223.6	–1.84	174.6	–7.52	194.6	3.07	0.76	3.80	593.6	–2.06
2010	223.3	–0.13	184.5	5.67	209.1	7.45	0.88	14.92	617.8	4.08
2011	223.5	0.09	190.1	3.04	215.2	2.92	0.93	6.38	629.7	1.93

Source: Based on US Energy Information Administration: Independent Statistics & Analysis

Notes

1. The figures were originally in billion ft^3 which have been converted to billion m^3 and rounded off (1 $ft^3 = 0.2831\ m^3$)
2. LDO means light diesel oil
3. Lease and plant fuel and the gas distributed through pipeline are excluded

Table 4.6 Industry-wise off-take of natural gas in India

Year	Domestic fuel		Industrial		Electric power generation		Fertilizer		Others	Total	
	Quantity (billion m^3)	Average annual growth during the preceding period (%)	Quantity (billion m^3)	Average annual growth during the preceding period (%)	Quantity (billion m^3)	Average annual growth during the preceding period (%)	Quantity (billion m^3)	Average annual growth during the preceding period (%)		Quantity (billion m^3)	Average annual growth during the preceding period (%)
1970	–	–	0.14	–	0.26	–	0.19	–	0.07	0.66	–
1980	0.01	–	0.22	5.7	0.49	8.8	0.61	22.1	0.20	1.53	13.2
1990	0.05	40.0	1.33	50.5	3.63	64.1	5.61	82.0	2.15	12.77	73.5
2000	0.34	58.0	3.80	18.6	8.80	14.2	8.48	5.1	6.44	27.86	11.8
2005	0.08	−15.3	5.11	6.9	11.88	7.0	7.76	−1.7	6.21	31.04	2.3
2006	0.44	450.0	4.76	−9.2	11.96	0.7	8.50	9.5	5.71	31.37	1.1
2007	0.04	−90.9	4.91	3.2	12.04	0.7	9.82	15.5	4.06	30.87	−1.6
2008	0.10	150.0	7.17	46.0	12.60	4.7	9.08	−7.5	3.78	32.73	6.0
2009	0.03	−70.0	1.89	−73.6	21.37	69.6	13.17	45.0	10.79	47.25	44.4
2010	–	–	–	–	–	–	–	–	–	51.20	8.4
2011	–	–	–	–	–	–	–	–	–	46.85	−8.5

Source: (1) Ministry of Statistics & Programme Implementation (Government of India): Energy Statistics, 2011; (2) Ministry of Mines (Government of India): Annual Report, 2011–2012 (for the data for 2010 and 2011)

Notes

1. The years refer to the period April to March of the following year
2. The total consumption (referred to as ‘utilized’) in 2009 has subsequently been marginally revised to 47.51 billion m^3, but industry-wise break-up has not been published till 2012
3. Industry-wise break-up of the consumption (referred to as ‘utilized’) in 2010 and 2011 has not been published till 2012
4. Industrial use of natural gas includes plant fuel, tea plantation and petrochemicals
5. Others include captive use, LPG shrinkage and compressed natural gas (CNG) sale for use in vehicles

land and under sea, which is again technology- and capital-intensive; moreover, such pipelines require sustained measures to protect against sabotage. Otherwise if it is used in the form of compressed natural gas (CNG) in cylinders for vehicular use, it is necessary to set up a network of storage and filling facilities (akin to petrol pumps).

(b) Liquid form: Liquid natural gas (LNG) or natural gas liquid (NGL) is made by cooling the gas to cryogenic temperature under high pressure. Seventeen kilolitres of gas at normal temperature condenses to 0.028 kl of liquid at (−)161 °C. This is economical from the transportation and storage point of view because a large volume of gas can be stored in a small space. On the other hand, the process of liquefaction is not only extremely difficult and costly but also extremely hazardous as LNG is highly inflammable and it has a tendency to explode. Consequently, its transportation and storage requires technology- and capital-intensive safety measures.

However, the dominant fraction of natural gas being methane, it contains four parts of hydrogen to one part of carbon. This makes it an environment-friendly energy source. One major gas pipeline can offset 120 tonnes of CO_2 if it displaces coal (Mottershead Chris). Now-a-days the emphasis is on combined cycle gas turbines (CCGT) by which the kinetic energy of heated natural gas is first used to drive turbines and then its thermal value is harnessed to boil water for generating superheated steam and driving another set of turbines. The efficiency of electricity output has reached the level of about 60 %. Now, triple CCGT power plant project is under construction in Japan which will precede the gas turbine by a solid oxide fuel cell stack. This project is expected to be operational in 2015 and the efficiency is expected to be as high as 70 %. But the main disadvantage of this triple CCGT system is that a high temperature of 500–1,000 °C will be required to activate the fuel cells.

4.1.4 Uranium

Uranium, the heaviest element known so far, has a fixed atomic number (92), but varying number of neutrons (commonly 143 and 146) and hence its two economically significant isotopes are U_{235} and U_{238} (the other isotope U_{234} is very unstable and not of economic significance). From the point of view of direct use for generation of energy, however, the naturally fissile U_{235} is the most important (U_{238} can also be used, but indirectly; see 'thorium' later in this chapter). It is extremely rare in its occurrence (its incidence in the Earth's crust is 4 ppm) and the common ore Pitchblende (a form of uraninite) mainly contains U_3O_8. It is only after the revolutionary 'special theory of relativity' of Einstein in 1905 that the potential of this metal as an agent of unimaginable energy was first foreseen. Subsequently, a series of experiments and achievements led finally to the realization of chain reaction by Enrico Fermi in 1942 and the first economic (?) use of this metal in the form of atom or fission bomb was witnessed in 1945 when the World War II came to an end.

Further research post-war resulted in atomic reactors in which heat energy could be released in a slow and sustained manner so that it could be harnessed to boil water to produce superheated steam which could then be used to generate thermal power. This was in contrast to the instantaneous and violent release of heat energy in bombs.

For the purpose of power generation in reactors, it has later been found that UO_2 containing U_{235} is also effective and the key to release of energy is the gamma rays emitted during fission (for making bombs, the oxide is not suitable). Although other compounds and some alloys are also suitable, yet their use is not common.

However, there are several problems associated with use of uranium for power generation as follows.

4.1.4.1 Distribution

Its occurrences are known but its minable deposits and working mines are limited to a few countries the important ones of which are shown in Table 4.7.

Some other countries also have reserves from which production is going on regularly. In India, as in 2012, mining is going on only in two areas–the area surrounding Jadugoda in West Singbhum district (Jharkhand) and Tummalapalle in Cuddapah district (Andhra Pradesh).

There are some unconventional sources of uranium like certain phosphate deposits (100–200 ppm in sedimentary rocks and up to 1,000 ppm in igneous rocks), seawater (3 ppb), black shale deposits and granite; but experiments have so far been limited to laboratories only. Special attention is being given by scientists to development of an absorbent material for recovering uranium from seawater since 1960s initially in Japan followed by Russia, China, Germany, UK, India, South Korea, Turkey and US. But none has emerged as economically viable so far.

Table 4.7 Uranium proved reserves

Country	Total proved reserve (tonnes)
Australia	1,074,000
Kazakhstan	622,000
Canada	439,000
South Africa	298,000
Namibia	213,000
Russia	158,000
Brazil	143,000
United States	102,000
Uzbekistan	93,000
India	78,000

Source: (1) FIMI, Jan 1, 2009 (for India); (2) World Nuclear Association 2011 (for other countries)

4.1.4.2 Recovery

The usable components in the ore are UO_2 and U-metal which need to be recovered from the ore through a complex process. There are two kinds of gangue materials associated with the ore–siliceous (as in Jadugoda) and carbonate (as in Tummalapalle). The recovery from the former type of ore involves acid leaching and the latter, alkali leaching. The acid leaching process is well established and the two plants in Jadugoda area are running well. But the alkali leaching is not popular because it requires a strong oxidant and the retention time is long. In India it has been recently commissioned in Tummalapalle and as in November, 2012, it has not stabilized. Another problem particularly in India is that this process requires caustic soda as the alkali and it is very costly here. Production is reported from all the countries shown in Table 4.7 and also from several other countries as can be seen in Table 4.8 later in this chapter.

4.1.4.3 Enrichment

In natural ore, the U_3O_8-content is very low–of the order of 0.5–1.0 % and the U-content may be as low as 0.1–0.2 %. Then this uranium metal contains only 0.718 % of the economically important U_{235}, the rest being U_{238} (99.278 %) and U_{234} (0.0056 %). Enrichment is about increasing the concentration of the U_{235}-content to different levels as follows.

(a) *Slightly enriched uranium (SEU)*: It has a concentration of 0.9–2.0 % and is used in some heavy water reactors for power generation.
(b) *Reprocessed uranium (RepU)*: It is a product of nuclear fuel cycles involving reprocessing of spent fuel recovered from light water reactors. The spent fuel contains slightly more U_{235} than natural uranium and can be used in certain types of reactor.
(c) *Low-enriched uranium (LEU)*: Its concentration varies from 3 to less than 20 %. The lower fraction (3–5 %) is used in the widely prevalent light water reactors while for use in research reactors higher concentration ranging from 12.00 to 19.75 % is required.
(d) *Highly enriched uranium (HEU)*: This involves enrichment to 20 % and beyond. For fast neutron reactors, the grade is about 20 % or somewhat more (in one type of fast reactor, 26.5 % is used). Naval reactors typically use 50–90 %. The fissile uranium in nuclear weapons usually contains at least 85 % (the atom bomb dropped at Hiroshima in 1945 contained 64 kg of 80 % enriched uranium). But in later generation weapons wherein $plutonium_{239}$ is used in the primary stage, uranium enriched to 40–80 % is used in the secondary stage. For criticality experiments, enrichment to over 97 % has been accomplished.

The technology for enrichment has been developed by a select few countries like US, Russia, China, UK, France, India, Pakistan etc. and it is kept as a secret. The first five belong to what is called ‘Nuclear Club’. Under the Non-Proliferation

Table 4.8 Uranium supply during 2004–2011 (by country)

Country	Production & demand of contained 'U' in ore and equivalent U_3O_8 (tonnes)								Change during 2004–2011 (8 years) [%]
	2004	2005	2006	2007	2008	2009	2010	2011	
Australia	8,982	9,516	7,593	8,611	8,430	7,982	5,900	5,983	–33.39
Brazil	300	110	190	299	330	345	148	265	–11.67
Canada	11,597	11,628	9,862	9,476	9,000	10,173	9,783	91,45	–21.14
China (estimated)	750	750	750	712	769	750	827	885	18.00
Czech Republic	412	408	359	306	263	258	254	229	–44.41
France	7	7	5	4	4	8	7	6	–14.29
Germany	77	94	65	41	0	0	0	52	–32.47
India (estimated)	230	230	177	270	271	290	400	400	73.91
Kazakhstan	3,719	4,357	5,279	6,637	8,521	14,020	17,803	19,451	423.02
Malawi	–	–	–	–	–	104	670	846	713.46 (change in 3 years)
Namibia	3,038	3,147	3,067	2,879	4,366	4,626	4,496	3,528	16.13
Niger	3,282	3,093	3,434	3,153	3,032	3,243	4,198	4,351	32.57
Pakistan (estimated)	45	45	45	45	45	50	45	45	Nil
Romania	90	90	90	77	77	75	77	77	–14.44
Russia	3,200	3,431	3,262	3,413	3,521	3,564	3,562	2,993	–6.47
South Africa	755	674	534	539	655	563	583	582	–22.91
Ukraine (estimated)	800	800	800	846	800	840	850	890	11.25
US	878	1,039	1,672	1,654	1,430	1,453	1,660	1,537	75.06
Uzbekistan	2,016	2,300	2,260	2,320	2,338	2,429	2,400	2,500	24.01
World total supply (uranium)	40,178	41,719	39,444	41,282	43,852	50,773	53,663	53,765	33.82
World total supply (equivalent U_3O_8)	47,382	49,199	46,516	48,683	51,716	59,875	63,285	63,389	33.82
World demand (U_3O_8)	–	75,691	73,834	76,067	76,053	76,763	81,135	74,575	–1.47
% satisfaction of demand (U_3O_8)	–	65	63	64	68	78	78	85	

Source: Based on US Energy Statistics & World Nuclear Association 2012
Note: The figures pertaining to Germany refer to supply from decommissioned reactors; all other figures refer to mine production

Treaty (NPT), the International Atomic Energy Agency (IAEA) monitors the facilities in all signatory countries other than the five members of the so-called Nuclear Club to ensure that they are not engaged in enrichment above the power grade and are not moving towards the weapon grade.

4.1.4.4 Trade and Supply

There are 45 countries which have either uranium ore or technologies of recovery/enrichment/reactor-construction and they have formed what is called Nuclear Suppliers' Group (NSG). All of them are signatories to the NPT. As per the provisions of the NPT, all trades in ore and technology have to be limited to this group only and the IAEA is responsible for monitoring it. So it is obvious that any country outside this Group has to be self-sufficient in both ore and technology in order to harness nuclear energy. In case a country is suspected to be moving towards development of bomb-grade uranium, it may face international sanctions imposed by the UN. Although India is neither a signatory to the NPT nor a member of the NSG, it has managed to get special exemption to import ore and technology under a Pact signed in 2008. As a result, the capacity factor of the 20 operational nuclear power plants of India, which plummeted to 50 % in 2008–2009, has bounced back to 78 % during January-September, 2012 with the help of uranium imported from Russia, France and Kazakhstan. But all countries outside the NSG are not so fortunate and for them, the restrictive supply situation is a formidable impediment to harnessing of nuclear energy.

4.1.4.5 Price

Since the supply of uranium does not depend only on the mine production so does not its spot price. Moreover, some extraneous factors can also determine its price. In the early 1990s when the cold war ended, US and Russia signed the Nuclear Disarmament Treaty under which both the countries were to dismantle their huge stocks of nuclear arsenal within a timeframe. Accordingly, large quantities of uranium were obtained from those decommissioned nuclear warheads. All of that uranium was released into the market suddenly increasing the supply followed by crashing of the price of uranium (in terms of UO_2) to $20/lb (as in July, 2007 the price was $136/lb and in December, 2010, it was ruling at around $65/lb).

4.1.4.6 Waste Disposal

Nuclear electricity generation creates large quantities of radioactive wastes at all stages of the nuclear chain from uranium mining to decommissioning of nuclear facilities. The most highly radioactive wastes are those which are produced in the core of the reactor. A total of 10,000 tonnes of spent nuclear fuel are being produced globally each year and the waste inventory is projected to be over 445,000 tonnes by 2020 (MGMI 2011). Yet no country has achieved an effective solution for the long-term management of spent nuclear fuel worldwide research notwithstanding. There are four categories of radioactive waste:

(a) *Naturally occurring radioactive materials (NORM)*: These are created by mining and milling of naturally occurring uranium ores.
(b) *Low-level wastes (LLW)*: These constitute the bulk of the volume of waste produced in the nuclear fuel chain, consisting of materials such as paper, rags, tools, clothing and filters which emit small amounts of mostly short-lived radiation.
(c) *Intermediate level wastes (ILW)*: These contain higher levels of radioactivity normally requiring shielding and includes resins, chemical sludge, metal fuel cladding and contaminated materials from the decommissioning of reactors or from nuclear reprocessing.
(d) *High level wastes (HLW) and spent nuclear fuel*: Both contain fission products and transuranic (atomic number greater than 92) elements generated in the reactor core.

Repository programmes for highly radioactive wastes mainly involve burial in deep geological formations in copper or steel containers (e.g. crystalline rock, clay formations) or old mines (salt, granite, clay, basalt mines) and these programmes are underway in Sweden, France, Finland, Switzerland, Canada, South Korea, Belgium, UK, Russia, India and China. But the practice has not yet come out as foolproof and a number of discouraging possibilities have been identified as under.

(a) Damage to adjacent rocks during excavation of the repository
(b) Corrosion of the containers by the radioactive waste
(c) Intense heat generated by radioactive decay and chemical/physical disturbance due to corrosion, gas generation etc.
(d) Escape of radionuclide through fractures and pores of the geological formations created due to build-up of gas pressure in the repository as a result of corrosion and degradation of organic material
(e) Poor understanding of the movement of the colloidal plutonium
(f) Unidentified faults and fractures in the rocks
(g) Effect of future earthquakes, glaciation etc.
(h) Accidental digging by ignorant future generations

Besides, the transportation of the waste to the repository sites is also a key issue to be addressed. In India, technology development is underway to build an underground repository about 1 km deep and for this purpose a laboratory in an abandoned mine is being planned.

Recently, in 2008, research in the Dundee University, Scotland indicated that fungi could colonize on uranium waste surfaces and transform it into nontoxic uranyl phosphate minerals. But commercial trial of this experiment has not been reported.

Scientists of the Bhabha Atomic Research Centre (BARC), India have reportedly found a novel way of recovering uranium from nuclear waste using a radiation-resistant microbe (*Deinococcus radiodurans*); the process termed a 'bioremediation of radioactive wastes' has allowed precipitation of 95 % uranium from extremely low uranium-containing effluents (*Hitavada*, Dec. 20, 2006). All such laboratory experiments should be pursued to confirm whether they are commercially viable or not.

4.1.4.7 Negative Public Perception

This is a problem haunting everybody all over the world. Negative public perception started from the first visible use of uranium in 1945 when two nuclear fissile bombs (popularly called 'atom bomb') were dropped in Hiroshima and Nagasaki at an interval of only 3 days. Deadly radiation reached over 10,000 Rad killing and incapacitating millions of humans through generations (humans die at exposure to 100 Rad). The memory has been repeatedly revived through numerous stories, photographs, media features and films, and the fear instilled in human mind has still not worn off. Then happened the accident in Three Mile Island, US in 1979 and the infamous industrial disaster in Chernobyl nuclear power plant in Russia's Siberian region in 1986. Now, the memory of the devastating effect of tsunami and earthquake (magnitude 9.0 on Richter scale) on March 11, 2011 on the Fukushima Daiichi plant in northern Japan is too vivid in human mind to generate any positive perception about the nuclear power. Under pressure from public, Japan government in 2012 has set a target to make the country nuclear-free by 2030. German government, which began switching from coal-based power to nuclear power under pressure from anti-coal environmental groups only recently, has closed down permanently eight of its older nuclear reactors and has decided to phase out the remaining nine by 2022 under pressure from another environmental group–anti-nuclear. A referendum in Italy has rejected a plan to generate 25 % of the country's electrical power from nuclear reactors by 2030. Swiss government has decided not to replace its five reactors when they reach the end of their useful lives. In India there has been sustained agitation during 2011–2012 by antinuclear groups against the Kudankulam reactor in Tamil Nadu; relatively richer uranium deposits located in Kyelleng-Pyndengsohiong and other adjoining areas in West Khasi Hills district, Meghalaya was first explored by the Atomic Minerals Directorate of Exploration and Development (AMDED) in late 1970s and early 1980s; but even after over 30 years is yet to come to production stage due to resistance of the local population.

4.1.4.8 Large Land Requirement

A nuclear power plant usually requires a land area of 36.32 ha for generation of every megawatt-hour of electricity.

4.1.4.9 Freshwater Requirement

An inland nuclear power plant may require over 1,000 l of freshwater for generation of every megawatt-hour of electricity.

All these problems notwithstanding, the positive aspects of nuclear power can by no means be underestimated. They are:

1. Nuclear power is clean in the sense that it does not emit greenhouse gases like coal or hydrocarbon-based power. As regards the danger from the radiation emitted from nuclear reactors and waste materials, there is some truth no doubt but more myths have been spread by misinformation campaign by ignorant or motivated environmental groups, media etc. In 1955, the UN General Assembly voted to set up a scientific committee that regularly assesses and reports on radiation dangers. These reports help to compare the magnitude of different sources of radiation. An examination of the risk in perspective reveals that over 500 detonations during the cold war pumped the global atmosphere full of deadly radioactive particles some of which are still emitting radiation. According to these reports, the total bomb radiation from decades of atmospheric testing is about 70 billion curies in contrast to 100 million curies released by Chernobyl nuclear plant in 1986, 50 million curies by the Three Mile Island, in 1979 and 10 million curies by the Fukushima Daiichi plant in 2011. True, there will be death and destruction in the vicinity of a leaking nuclear reactor, but technology has advanced a lot and is still advancing to increase the safety of modern reactors. The paranoia about radiation, witnessed in villages against not only reactor-construction but also mining of uranium and even its exploration, is not therefore based on any informed risk assessment.
2. The shore-based nuclear reactors (Advanced Heavy Water Reactor or AHWR) can yield a vital by-product namely desalinated potable water. For desalination, the excess power generated by the power plant itself is utilized. Such projects have been undertaken by the Bhabha Atomic Research Centre (BARC) in India.
3. Uranium is a high-value low-volume material and very small quantities are required for power generation (theoretically, 1 g of U can generate 2,300 KWh of electricity). So, a large inventory can be maintained in a small space unlike coal, oil, natural gas etc.
4. The U_{238} isotope present in the uranium ore is carried into the enriched uranium and the reactor. It does not have a direct role in fission, but surplus neutrons freed from the atoms of the U_{235} during its fission process, hit the atoms of the surrounding U_{238}. This triggers its transformation into unstable neptunium (Np_{239}) and finally into stable plutonium (Pu_{239}) which is amenable to fission and can be used in fast reactors for generation of power. Separation of the plutonium from the nuclear waste is a high-tech process and only a select few countries are privy to it.
5. During enrichment, the percentage of U_{235} is increased at the cost of U_{238-}, part of which goes into the tailing. This rejected U_{238} is called depleted uranium (DU) and is a useful by-product of enrichment process. It contains much lower U_{235} and

hence much less radioactivity than in natural uranium. Normally, the radioactive emission of DU is 60 % compared to natural uranium and can even be less depending on the degree of enrichment. According to World Health Organization (WHO), there is no risk due to exposure to DU. Its civilian uses include counter-weights in aircraft, radiation shielding in medical therapy and industrial radiography equipments, containers for transporting radioactive material while its military uses include defensive armour plating and armour-piercing projectiles.

The net effect of the positive and negative factors associated with nuclear reactors is that the world as a whole cannot fulfill its energy demand without this source at least until alternative sources of energy can make up the shortfall. As in September, 2010, there were 438 operational nuclear reactors in 31 countries with a total installed capacity of 372 GW. These reactors are generating and supplying electricity for the general public, agriculture and industries without any glitch. These reactors are getting their supplies of uranium from both within and outside. Table 4.8 shows the supply–demand scenario in the world.

Table 4.8 brings out certain facts. The overall world supply has increased significantly during the eight years before 2012 but the demand remained more or less stable. Still, the supply (mainly from the mines) has been far short of the demand. Shortfall is made up by blending with decommissioned military stocks (largely in Russia) and by reprocessing of spent fuel into mixed oxides fuel. Amongst the countries, mainly the members of the Organization for Economic Cooperation and Development (OECD) have shown decline in supply in contrast to the US and most of the developing countries. Germany was on a sudden decommissioning spree in 2011 when the Fukushima disaster took place.

In fact, the countries that are building new nuclear power capacity include many non-OECD countries. The country with the largest number of planned facilities is China with 26 reactors under construction, 52 reactors planned and 120 reactors proposed. If the trend continues, China's capacity should be almost double that of US, currently the world's largest producer of nuclear electricity. The two countries behind China in adding new reactors are Russia (10 under construction, 14 planned and 30 proposed) and India (five under construction, 18 planned and 40 proposed). Bangladesh, Pakistan, Turkey, Vietnam and many other emerging-economy countries are also planning new reactors.

4.2 Unconventional Sources

4.2.1 Methane

Methane (CH_4) contains even less carbon and more hydrogen than natural gas and hence it pollutes the air much less. Being one of the greenhouse gases, when allowed to escape to the atmosphere, it adds to the green house gas concentration.

Methane is used in power generation, fertilizer manufacturing, cooking gas and many other industrial processes in the same way as natural gas. The sources of methane are discussed as follows.

4.2.1.1 Coal Bed Methane

Coal bed methane or CBM refers to the entrapped methane held in coal bed in monomolecular state (i.e. not as free gas) and its economic exploitability depends on the following five factors.

(i) Methane content should be high–15–30 m^3/tonne at cut-off of 6 m^3/tonne.
(ii) Permeability should be good–15–30 mD (cf. +100 mD in exploitable oil reservoir; +5,000 mD in unconsolidated sand).
(iii) Depth of the coal bed should be less than 1,000 m because the high pressure at greater depths would tend to close the cleat structure and reduce permeability.
(iv) The coal should otherwise not be economically minable.
(v) The rank of coal should be preferably bituminous, but anthracite is also amenable.

In US, it was extracted commercially first in 1985, followed by Australia and China. The annual production in the US stood at the level of 49.67 billion m^3 during 2005–2007. During 2012, the rates of production in some of the countries are shown in Table 4.9.

In addition, Canada also produces CBM. According to Camac Energy Inc, the world CBM production is expected to be around 146 billion m^3.

Insofar as India is concerned, the ONGC carried out investigations in some of the coalfields till 2006 and the results are shown in Table 4.10.

In 2009, a US scientist named Craig Venter announced the discovery of the role of a kind of bacteria which have a unique enzyme capable of breaking down coal to form methane. According to him, one group of bacteria eat coal and break it down into organic acids, hydrogen and CO_2 which are then taken by another group of organisms with enzymes to make methane. Thus produced, the methane is called 'microbially enhanced coal bed methane'.

Table 4.9 Rate of CBM production during 2012 (in selected countries)

Country	Average rate of production (million m^3/day)	Number of years after which production level has been achieved
United States	141.6	27
China	4.1	20
Australia	17.0	8
India	2.8	4

Source: International Energy Agency (IEA) 2012

Table 4.10 CBM content and resource in Indian coalfields

Coalfields where CBM blocks were investigated and located	CBM-content (m^3/tonne)	CBM resources (billion m^3)
Jharia	7–17	85
East Bokaro	10–15	45
West Bokaro	2–10	
North Karanpura	6–10	106
South Karanpura	–	30
Raniganj	–	115
Sohagpur	–	159
Wardha	–	20
Satpura	–	29
Sonhat	–	50
Barmer (lignite)	3–8.5	270

Source: Director General of Hydrocarbon, Government of India (Pande 2007)

The large production in US is mainly helped by tax incentives extended by the Government. While announcing the policy for CBM in 1997, the Government of India also offered some fiscal and regulatory incentives which include:

(i) No participative interest from the Government
(ii) Seven-year tax holiday from the date of commencement of commercial production
(iii) Commercial bonus of US $300,000 on declaration of commercial assessment
(iv) Exemption of customs duty on imported equipments
(v) 100 % foreign direct investment for CBM exploitation.

As regards status of resource and investments, Table 4.11 shows a comparative picture in the Asian countries. All the countries offer one or the other kind of fiscal incentives.

4.2.1.2 Working and Abandoned Coal Mine Methane (CMM & ACMM)

It is the methane released during and after mining activity and is generated automatically in many mines. This methane, being highly hazardous, is first and foremost a safety issue. Technologies have been developed to capture and utilize it for various industrial purposes like power generation, town gas, vehicle fuel, and coal drying. Moreover, the technologies are eligible to earn carbon credits because they serve to avoid the release of methane into the atmosphere thereby adding to the greenhouse gas concentration. In US, during 2003, approximately 1.1 billion m^3 of CMM was captured and utilized. Besides, there is a number of projects underway in different countries with the aim of not only generating industrial value but also earning carbon credits (see Table 4.12).

Table 4.11 Regional comparison (resources and investments)

Country	Resources (trillion m^3)	Number of contracts signed	Stage of operation	Investment (US $)
Indonesia	12.7	7	Exploration and feasibility study (as in 2009)	20 million (commitment, 2009–2011)
China	28.3	29	First production in November, 2005	342 million (actual up to 2007)
India	8.5	26	First production in July 2007	150 million (commitment)
Vietnam	Unknown	2	Exploration and feasibility study (as in 2009)	1.5 million (commitment)

Source: Dipesh Dipu: Coal Bed Methane–from a Liability to an Asset, *Mining Engineers' Journal*, India, November, 2009

Table 4.12 Ongoing projects for capture and industrial utilization of methane from coal mines (February, 2009)

Country	Number of CMM projects	Number of ACMM projects	Total amount of emission avoided (million tCO_2e/year)
Australia	10	5	6.4
China	40	0	8.6
Czech Republic	1	0	1.4
Germany	9	36	7.5
Kazakhstan	1	0	0.2
Poland	21	0	2.1
Russia	7	0	0.7
Ukraine	9	0	1.9
US	13	26	16.4
World total	111	67	45.2

Source: International Energy Agency, Information Paper: CMM in China–Budding Asset with Potential to Bloom; February, 2009
Note: "tCO_2e" stands for "tonnes of CO_2 equivalent"

As regards, abandoned mine methane, 200 MW power project fired with it have already been developed in Germany.

4.2.1.3 Ventilation Air Methane (VAM)

It is the largest source of methane emissions from the ventilation systems of underground coal mines. The World Coal Institute (2009) estimated the annual emission in the world at about 300 million tCO_2e and it represents about 60 % of all methane emissions, China alone accounting for 24 % followed by US, Ukraine, Australia and

Russia. The methane content in ventilation air is typically about 1 % or less, which is as such not economically usable. But since methane is much more potent than CO_2 as a greenhouse gas, its reduction is eligible for carbon credit and the efforts are, therefore, directed to reducing its release into atmosphere. In US, a technology termed VAMOX has been developed to heat the ventilation exhaust air containing methane to yield less potent CO_2 and water vapour. As a result the effective reduction in greenhouse gas is 18 tCO_2e for every tonne of methane. Since the oxidation reaction is exothermic, the heat generated can sustain the process.

4.2.2 Thorium

Commercial deposits of thorium (Th_{232}) occur essentially in the form of a complex mineral namely monazite which is a phosphate of various rare earth metals, uranium and thorium along with its isotope mesothorium. There are abundant resources of monazite in the beach placer deposits of India as well as of Sri Lanka, US, Australia, South Africa, Brazil etc. Thorium and also mesothorium can be harnessed as nuclear fission energy. Th_{232} is poorly radioactive (half life 13.9 billion years) and cannot therefore by itself sustain chain fission. It has to be first converted to the fissionable substance U_{233}. For this purpose, there are three methods:

(a) *Thermal reactor*: Th_{232} is first used in a thermal reactor with U_{235} which releases neutrons some of which take part in chain fission and the remaining ones hit the Th_{232} converting it to U_{233}. The latter can be chemically separated and thereafter can be used in an independent thermal reactor.
(b) *Fast breeder reactor*: The Pu_{239} produced in a uranium thermal reactor (see 'Uranium/positive aspects' earlier in this chapter) emits fast neutrons and may be used in conjunction with Th_{232} in a fast breeder reactor. Here also U_{233} is produced. The neutrons emitted by the latter not only by itself sustain chain fission but also hit the unconverted Th_{232} converting it to more U_{233}. After triggering the initial fission, no more Pu_{239} will be required. But, since the thermal reactors generally use UO_2 as the fuel, the Pu_{239} will also be in the oxide form which is less efficient than its metallic counterpart.
(c) *Accelerator-driven system (ADS)*: In this technology, thorium is used independently in a reactor. For enabling Th_{232} to attain criticality so that it can sustain chain fission, "spallation" (see glossary) from an external source of neutrons is needed. The technology of building an accelerator, which is the first step, is yet to be developed.

The challenges are either to chemically separate and retrieve the U_{233} from a uranium reactor (first method) or to recover Pu_{239} metal from its oxide (second method) or to develop the technology for ADS (third method). In India, a fast breeder reactor is under construction in Kalpakkam, Tamil Nadu. After this reactor becomes critical and more such reactors are built up, that will create an opening for utilizing the vast resources of monazite in India.

4.2.3 *Oil Shale (or Kerogen Shale or Shale Oil)*

Oil shale is a type of shale formed in brackish/freshwater environment and rich in kerogen which has not yet transformed to petroleum. It can be mined by open cast or underground method just like coal and from it liquid hydrocarbon called 'shale oil' can be extracted. Well-explored economic reserves of oil shale are fairly widely distributed in Western US (Green River), Australia (Queensland), Sweden, Estonia, Jordan, France, Germany, Brazil, China, Southern Mongolia and Russia. World oil shale resources were equivalent to more than five trillion barrels of oil in situ, of which over one trillion barrels may be technically recoverable (IEA 2010).

The European oil shale industry had a long history albeit in a small scale. The industry expanded during the first half of twentieth century due to limited access to petroleum and the mass production of automobiles and trucks. But its production was discontinued in many countries only to be revived when petroleum prices increased several fold in 1973. World peak oil shale production was 46 million tonnes in 1980 before again slumping to 16 million tonnes in 2000 when the industry was discontinued in most of the countries mainly due to competition from petroleum and other sources of energy. The history of oil shale industry till 2000 is summarized in Table 4.13.

The reasons for discontinuation of oil shale industry can be traced to the five formidable challenges as follows.

(a) Economic: Cost of extraction of oil from oil shale is very high and it does not compete with petroleum unless either the price of petroleum is very high or its supply is not accessible for geopolitical reasons.
(b) Environmental: Problems, like in coal mining and burning, include land use degradation, waste disposal, wastewater management, greenhouse gas emission, air pollution, acid drainage, mercury contamination of surface water and ground water. In 2002, in Estonia, the largest producer and consumer of oil shale,

Table 4.13 History of oil shale industry in the world till 2000

Country	Year of commencement of production	Year of discontinuation of production
France	1837	Discontinued long ago but year not known
UK (Scotland)	1880	1955
Estonia	1930	Continuing
China	1930	Continuing
Sweden	1940	1965
Russia	1945	2000
Germany	1950	1990
US	1986	1991
Brazil	1990	Continuing

Source: www.google.com/wikepedia

about 97 % of air pollution, 86 % of total waste and 23 % of water pollution came from the oil shale-fired power industry.

(c) Content of organic matter: The organic matter is the source of oil and its ratio to mineral matter lies approximately between 0.75:5.0 and 1.5:5.0; and the hydrogen to carbon ratio (H/C) is 1.2–1.8 times lower than that for crude oil and 1.5–3.0 times higher than that for coal.

(d) Content of injurious substances: The sulphur- and arsenic-contents in shale oil is high. The sulphur content in the shale oil from Jordan is as high as 9.5 % and that from Green River 0.76 % (cf. 0.42 % in Texas crude petroleum). This implies higher treatment cost of shale oil before it can serve as a oil refinery feedstock.

(e) Water consumption: The process of distilling and heating of oil shale is highly water-intensive and may not be feasible in arid regions. In 2002, the oil shale-fired power industry consumed 91 % of the water consumed in Estonia. It has been estimated that the water consumption is 1–5 barrels per barrel of shale oil extracted.

The oil shale industry has started again to revive since the beginning of the twenty-first century. The status of production and uses of oil shale are shown in Table 4.14.

By the following year (2009), Estonia has become the leading producer and user of oil shale accounting for 80 % of the global production and the country's oil

Table 4.14 Country-wise production and status of uses of oil shale

Country	Production (tonnes) as in 2008 (except in US)	Industrial uses
China	375,000	Oil production, power generation (12 MW), cement, chemical
Estonia	355,000	Oil production, power generation, cement, chemical
Brazil	200,000	Oil production
Germany	–	Power generation (9.9 MW), cement
Russia	–	Power generation (discontinued), chemical
Canada	–	Power generation after blending with coal (planned)
Turkey	–	Power generation after blending with coal (planned)
Jordan	–	Power generation (construction planned)
Egypt	–	Power generation (construction planned)
Israel	–	Power generation (discontinued)
Romania	–	Power generation (discontinued)
Australia	–	Oil shale project put on hold in 2004 under pressure from environmental groups
United States	10,000 barrels/day (2012)	Production on trial after the restrictive 'Oil Shale Plan' has been published by the Bureau of Land Management, US.

Source: (1) Free Press, Canada, Nov 16, 2012 accessed through www.google.com (for US); (2) World Energy Council 2008 (for other countries) shale-based power generation capacity has reached 2967 MW accounting for 95 % of total capacity. As at the end of 2012, no commercial interest has been taken in India to even explore for oil shale occurrences because of mainly abundant coal reserves and environmental deterrence. Instead, coal-to-oil projects are considered more attractive here.

4.2.4 Tight Oil (or Shale Oil)

In contrast to petroleum which occurs in sandstone, this term is used for oil-bearing shale i.e. the shale deposits which contain petroleum (unlike oil shale which contains kerogen) that is sometimes produced from drilling wells. According to IEA, its production in US was 8.1 million barrels/day from some oil-bearing shale formations in North Dakota and Texas. But till the end of 2012, this has not become a popular energy source in the world.

4.2.5 Shale Gas

Shale gas refers to gas occurring naturally in shale. It was first extracted in Fredonia, New York in 1825 in shallow low-pressure fractured zones. But in 1970s when production potential from the hitherto known conventional natural gas reservoirs in US started declining, interest in this unconventional gas was revived and intensive R&D and demonstration projects were launched with a view to development of suitable technology for commercial production. This led to the micro-seismic imaging, air-drilled micro-fracture, massive hydraulic fracturing and slick-water fracturing techniques. Special technologies were necessary because unlike in case of conventional natural gas, the natural porosity and permeability of the reservoir rock in case of shale gas is very low. The US Government also announced fiscal incentives. All these developments led to the first commercial shale gas well in Texas in 1998. Thereafter, shale gas has become the fastest growing contributor to total primary energy (TPE) in the US. In 2005, there were 14,990 shale gas wells in US which increased by 4,185–19,175 wells in 2007. Table 4.15 tracks the growth and projection of the shale gas industry in US.

US EIA estimated the technically recoverable resource as in 2012 at 13.65 trillion m^3. The development of shale gas industry has become a game changer in international market. From deficit, the country has within a short time become energy-surplus and this change has a far-reaching global impact. Because of increase in production, the price of its closest rival namely natural gas has fallen in US market (price plummeted from $ 13/mmbtu in 2006 to $ 4/mmbtu in 2010); as a result power plants there are preferring natural gas to coal and the coal has become surplus; consequently the coal mining companies have now started exporting it to China at cheaper price; this has reduced China's import of coal from Australia

Table 4.15 Growth of US shale gas industry

Year	Quantity of shale gas produced (billion m^3)	% share of shale gas in the total gas production
1996	8.5 (from demonstration project)	1.6
1998	First commercial drilling	–
2006	31.0	5.9
2008	57.0	–
2010	150	23
2035	–	49

Source: (1) US Energy Information Administration (EIA): *Energy Outlook*, 2013; (2) MGMI, Jan.–March, 2013

forcing the Australian coal mining companies to cut both production and jobs (London Commodity News, August 23, 2012).

In 2013, China has set up a target of boosting its annual production from near zero to 60 billion m^3 by 2020. The Chinese government has estimated the country's shale gas reserve at 25 trillion m^3, but the shale formations so far drilled have been analyzed to have a high clay-content which may make them less amenable to fracturing and for China to fulfill its target, the technologies may have to be modified and improved (MGMI 2013).

In India considerable importance is being accorded by the Government to shale gas exploration. Geological Survey of India has prognosticated an in-situ resource of 1.52 trillion m^3 within the Barren Measures (Ironstone Shale) in Gondwana basin in the south-western part of Raniganj Coalfield (Mondal 2011). Other areas considered as prospective include Cambay basin, Krishna-Godavari basin, Assam-Arakan basin, Gangetic plain, Rajasthan and Damodar basin. In the latter basin, ONGC has started exploration for shale gas. The Government has signed a Memorandum of Understanding (MOU) in 2010 with US Government for exploration in some Indian basins by the US Geological Survey. Indian private sector initiatives include signing of an agreement by Reliance Industries Ltd with Pioneer Resources Ltd of US for forming a joint venture company along with Newpeck, Mexico for the stake in the Eagle Ford shale gas field for drilling and development. The public sector company ONGC Ltd has signed an MOU with US-based ConocoPhillips for exploring shale gas prospects in India and US. In October, 2012, two other public sector companies Oil India Ltd (OIL) and Indian Oil Corporation (IOC) have acquired 30 % stake in the shale gas assets of the US firm Carrizo Oil & Gas in the Niobrara basin in Colorado. A fourth public sector company namely Bharat Petroleum Corporation has acquired shale gas block in Australia in 2010 and started exploration there. Thus the year 2010 has seen a spurt in initiatives by Indian companies to capture and occupy some space in the shale gas sector.

In March 2013, the Government of India has formulated a draft shale gas policy the main features of which are market-determined pricing and production-sharing net of all statutory dues (MGMI 2013).

4.2.6 Tight Gas

Tight gas is similar to shale gas except that its reservoir rock is sandstone instead of shale (rarely tight gas is trapped in limestone also). Tight gas differs from natural gas in the nature of the sandstone. In case of natural gas, the sandstone belonging to Tertiary formations is incompact and permeable enough to facilitate its easy recovery under natural reservoir pressure; but the sandstone housing tight gas belongs to Palaeozoic formation and was subjected to compaction, cementation and recrystallization. Permeability of the reservoir sandstone rarely exceeds 0.01 mD and may even be as low as one nano-Darcy. Recovery of tight gas, therefore, requires hydraulic fracturing, acidizing and secondary production techniques.

Once written off as uneconomic, it is now emerging as an important source of energy (like shale gas). The IEA has estimated the recoverable tight gas reserve in US at 8.75 trillion m^3. In 2006, the annual tight gas production in US stood at about 108 billion m^3 accounting for approximately 19 % of the total gas production there (Misra, 2012). Other countries like Canada, Australia and China are also paying attention to this source of energy. India has only recently started to focus on its investigation. According to Misra (2012), the potential formations include Bhuvangiri Formation (permeability 0.033 mD) and Albian Andimadam sandstone in Cauvery basin, Mandapeta sandstone in Krishna-Godavari basin (permeability 0.01 mD), Mukta and Bassen formations in Mumbai offshore basin, Wadu unit in Cambay basin and Jabera in Vindhyan basin.

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Chapter 5
Minerals and Energy—Renewable Sources

The renewable sources of energy are of following types.

1. Conventional (traditionally established)
   - Mega-hydro power
   - Micro-hydro power
   - Firewood and charcoal
2. Un-conventional (recent)
   - Solar power
   - Wind energy
   - Bio-fuel (biomass)
   - Fuel cell (electrochemical energy)
   - Hydrogen
   - Fusion power [Deuterium; Tritium; Helium; and Ultra-dense deuterium (UDD)]
   - Methane hydrate (or gas hydrate or clathrate)
   - Geothermal energy
   - Ocean energy [Tidal; Ocean thermal energy conversion; Wave; Salt gradient]
   - Bacteria
   - Industrial waste heat
   - Wood and wood pellet

   The pros and cons of all these sources are discussed in this chapter.

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5.1 Conventional Sources

5.1.1 Mega- and Micro-hydropower

Hydroelectric power is renewable because it is based on the concept of potential energy gained by water as it flows down from higher to lower altitude; and the source of the water is either glacier or rain—directly or indirectly. For sustainable generation of energy, dams are built to hold the excess water in reservoirs and heavy turbines are installed (here comes the role of minerals). The hydropower is renewable because glaciers are replenished every winter and rain-fed rivers are recharged whenever it rains in the catchment area. But in times of successive droughts the reservoirs may dry up and glaciers, considered from a long-term point of view, are also tending to recede due to global warming and other reasons. Consequently, hydropower is not independent of climatic conditions.

Mega- and micro-hydropower stations differ in scale and, consequently, in utilities and adverse fallouts. These are as follows.

(a) *Gestation period:* For obvious reasons, a large scale mega dam requiring thousands of tonnes of material and hundreds of men will take several years to complete in total contrast to a micro dam. The gestation period for the former may extend indefinitely for reasons of resolution of land acquisition, environmental and ecological concerns—a trend becoming more the rule than exception in countries like India.

(b) *Electricity generation:* The capacities of mega-hydroelectric stations are in hundreds of megawatt and the electricity can be made grid-interactive implying that its frequency is consistent with that of the electricity from other sources and can be easily wheeled into transmission grid. The capacity of the largest generator unit in China is 800 MW. Capacities of micro-hydropower units built at local village level, on the contrary, are in a few kilowatts or at best a few megawatts and being of low and fluctuating, voltage it is difficult to maintain the normal grid frequency and such units are best suited to off-grid applications (however some of the modern projects using standard technology generate power which, with the help of transformers, can be made grid interactive). A station which was under construction in November, 2012 in the Upper Nilgiri Hills of India, will generate 42 MW; 84 stations in Lamtung district of Nepal together generate 2,408 KW lighting 22,769 houses; and one project in West Sulawesi province of Indonesia is planned (November, 2012) to generate 30 KW power.

(c) *Irrigation potential:* Mega-hydropower stations can store sufficient water so as to irrigate a large area unlike their micro-scale counterparts. But this is turning out to be a bane in case of large old dams built in the 1950s, 1960s or 1970s. The river water has to be diverted for irrigation through a network of canals. According to a report (WWF 2010), this has resulted in fall of the water table and death of many underwater species in the downstream basins of at least 10 largest rivers namely Danube, Yangtze, Rio Grande, Salween, Nile, Indus, Ganges, Plata and Murray-Darling; Nile that used to carry 32 billion m^3 of water a year now carries only 2; Indus in Pakistan has lost 90 % of its water in 60 years; in the Ganges, 60 % of the river-flow is diverted in canals for irrigation (Bharti 2011).

(d) *Direct monetary costs:* Mega hydropower stations require large and high dams and large heavy-duty turbines to be constructed along with a wide range of paraphernalia. Hence their capital cost is high. This implies long amortization, running costs per unit electricity generated is relatively higher than in micro stations at least till the investment is fully amortized. The cost of the largest station in Brazil under construction on Amazon River will be $12.6 billion if completed on schedule (costs in 2012). The micro stations are low-cost facilities constructed at village level having off-grid applications and they require relatively small capital investment which is quickly amortized.

(e) *Environmental and ecological costs:* Although this method of generation of electricity does not pollute the air and water, yet large areas of forests may be submerged and lost in case of mega stations, unlike their micro counterparts. Besides, the reduced flow of the river downstream of a dam, along with the forests will go without bio-diversity. The costs of resolving the ecological problems associated with irrigating large areas through network of canals from the large reservoirs of mega dams in US have become so high that the US government has stopped constructing new dams and, of the existing 5,500 dams, over 465 old ones have been demolished (Bharti 2011).

(f) *Social costs:* Large areas with villages may be submerged under reservoir of mega-hydropower stations involving displacement of large number of people which requires long time to settle—extending even to decades and this is the primary reason for cost overruns. This is the bane of construction of such stations. The above-mentioned dam in Brazil will submerge 500 km^2 of area and displace 40,000 people. There is no such problem in case of the micro stations.

(g) *Siltation:* A mega dam holds a large volume of flowing river water behind it for a long time. As a result, the sediments carried by the river are all deposited behind and at the bottom of the dam reducing the storage capacity of the reservoir, its power generating efficiency and also the soil health of the land downstream by depriving them of fresh sediments rich in nutrients. Frequent de-silting is highly cost-intensive and adds to the maintenance costs of a large aging hydropower station. The micro stations suffer from no such disadvantage.

(h) *Natural factors:* The mega stations can be built in mountainous as well as plain terrain, the only condition being large rivers with high banks. The natural velocity of flow of a river is not an overriding technical condition because the height of the dam and volume of the reservoir water generate the necessary force to drive turbines. Micro stations however can be built on small natural streams gaining the force required to drive turbines, to a great extent, from their natural velocity which is possible in mountainous terrains. Therefore, both are location-specific but the latter by a greater degree.

(i) *Groundwater salinity:* The water-flows of long ocean-going rivers decrease in the estuarine areas due to interference by mega dams upstream. Consequently, seawater is no longer flushed out of estuaries and it intrudes into groundwater. There is no such problem in case of micro dams.

(j) *Risk of dam-burst:* The disastrous consequences of bursting of an old mega dam may be very hugely catastrophic. Regulated discharge of water is a standard practice when surplus water builds up pressure on the dam. But unlike in case of a new dam, an old dam may give in the pressure suddenly and burst without advance notice particularly at times of heavy rains in the upstream area. The sudden man-induced flood along the lower course of the river may cause huge losses of men, animals and land. Such risks in case of micro dams are practically nil.

(k) *Rivers flowing across international and interstate boundaries:* There are a number of long rivers like Nile, Indus, Brahmaputra etc. which flow across international borders. A mega-dam built on such a river by any country would affect the flow of water along that river in other countries. This may create conflicts of interest among the stakeholder countries necessitating protracted international negotiations and international treaties before construction of the dam. Similar is the problem in case of rivers flowing across boundaries of the states in India (e.g. Cauvery, Krishna).

All said and done, according to IEA as reported in *Free Press Canada* (Nov 16, 2012), hydropower accounted for only 2.2 % of the total energy generated in the world in 2008 which increased to 6.0 % in 2011; and hydroelectric dams will be the second biggest electricity generator in 2015 after coal. However, if only electricity generation (instead of total energy) is considered, then hydroelectricity production accounted for 16.3 % of world's electricity as in October, 2012 when it was the leading renewable energy generation technology in 159 countries; and the global hydroelectricity generation is projected to double in 2050 (IEA and Ministry of Mines and Energy, Brazil 2012). In Brazil, when the dam on Amazon River is completed, it will fulfill 78 % of Brazil's electricity demand; and in Japan 8 % of electricity demand is met through this source. Growth of hydropower capacity in India during 1970–2010 is shown in Table 5.1.

The negative growth during the year 2009–2010 is due mainly to (i) decrease in generation because of drought and low water level in some of the reservoirs; and (ii) stalling of projects on account of environmental, ecological and social factors. During the same period (i.e. 2009–2010), India's installed capacity of grid interactive power generation through micro hydro-projects increased from 2,181 to 2,735 MW registering a growth of 25.40 % (NSO 2011).

The environmentalists claim that hydropower projects should not be built for any other purpose than electricity generation. According to them, if after electricity generation the water is allowed to flow downstream without diverting it through canals, then the long term ecological costs can be avoided. They also emphasize on more and more micro hydropower projects.

Table 5.1 Growth of the world's and India's mega-hydropower capacity

Year	World		India	
	Generation capacity (TW)	Average annual growth with reference to the previous data (%)	Generation capacity (MW)	Average annual growth with reference to the previous data (%)
1971	–	–	6,383	–
1976	–	–	8,464	6.52
1981	0.60	–	11,791	7.86
1986	–	–	15,472	6.24
1991	–	–	18,753	4.24
1996	–	–	20,986	2.38
2001	–	–	25,153	3.97
2004	0.93	2.39	–	–
2006	1.0	3.76	32,326	5.70
2009	–	–	36,878	4.69
2010	–	–	36,863	–0.04
CAGR during 1970–2010				4.48

Source: (1) National Statistical Organization (NSO), Government of India; (2) Energy Statistics, 2011 (for India); (3) US Energy Information Administration (for world)

Notes

1. *In India the years refer to those ending on 31st March*
2. CAGR stands for Compound Annual Growth Rate

5.1.2 *Firewood and Charcoal*

Firewood is a specific kind of biomass (see later in this chapter) comprising the logs of hard wood and charcoal is a product based on this. In olden times, these fuels were used not for electricity generation but for heating and river transportation. In traditional manor houses (and also other houses) in the West firewood was the fuel used in fireplaces. Even today, for about three billion people mostly in innumerable villages of Asia and Africa, where electricity, coal and gas continue to be inaccessible to the people, firewood is a cheap (or even free) source of energy used for cooking. And in India, the Hindus use mostly wood for cremating dead bodies. However it is a highly polluting fuel emitting CO, NO_x, volatile organic compounds (VOC), black carbon etc. Besides, it is a wasteful practice of energy utilization because as much as 66 % of the energy is actually wasted.

5.2 Unconventional Sources

5.2.1 Solar Power

Solar power is essentially a manifestation of nuclear fusion which is constantly going on inside the sun. The issue is how to transform sunshine into usable electricity. The current and emerging technologies are as follows (Hopwood et al. 2012).

(a) Photovoltaic (PV): It uses arrays of PV modules mounted on buildings or ground-mounted solar parks.
(b) Concentrated solar thermal power (CSP or CST): It uses concentrated solar energy to make steam for generating electricity like any other thermal power plant. It uses parabolic mirrors for concentrating solar energy.
(c) Concentrated photovoltaic (CPV): This is an emerging technology.

Solar power is 100 % environment-friendly. Solar industry is the fastest growing renewable energy industry. Many industrialized nations are installing significant solar power capacities in their grids as a supplement or an alternative to other power sources and more particularly during 2010–2011, there is a surge in growth of solar power worldwide as shown or Table 5.2.

It appears somewhat paradoxical that solar power has not caught up with the African countries in spite of the fact that electricity is still inaccessible to 66 % of Sub-Saharan population and 92 % of rural African population and that there is vast tracts of uninhabited land (population density 30.51/km^2) receiving abundant sunshine (JRC 2011). The reasons may not be far to seek. Despite the phenomenal growth in many countries as shown in Table 5.2, there are some limiting factors from which solar power suffers. These are as under.

(a) *Solar panel hardware:* High-efficiency photovoltaic cells require ultrahigh purity (99.9999 %) single crystal silicon rod cut into ultrathin wafer (180–350 μm); and such silicon can be made from quartz of very high purity, not available everywhere. The preparation of single crystal silicon rods also requires some special technology—Czochralski method or float zone refining method. Then the rod has to be doped with boron to convert photons into light. However, relatively low-efficiency cells meant for ordinary purpose can be made from less pure quartz, but the technology is the same (Chatterjee 2009).
(b) *Land:* Industrial scale solar power plants (not the rooftop panels and suchlike for off-grid applications) require large areas of land. They, therefore, have to compete with other land-uses. As a thumb rule, one MW PV-based solar power plant requires 5–10 acres of land while concentrated solar thermal power (CSP or CST) has been found in US to need 2–4 ha per MW.
(c) *Cost:* After decades of intensive research, the energy efficiency of silicon cells has, until 2007, improved from 6 to 18 % only. Besides, the existing technologies for making crystalline silicon is expensive and research to develop low-cost technologies, although underway, is yet to yield results. Consequently, the

Table 5.2 Growth of the world's solar power capacity during 2010–2011

Country	PV power capacity (MW)		Growth	% share	Remarks
	2010	2011	(%)	in the world during 2011	
World	39,778	68,410	71.98	100	The phenomenal growth of solar power in practically all the countries listed here and the world as a whole is mainly the result of fiscal incentives granted by different governments.
Australia	504	1,200	138.10	1.75	The largest station is 10 MW of capacity. But the Government has mooted a plan in 2009 to build a station with 1,000 MW capacity at an investment of US $ 1.05 billion.
Belgium	803	1,812	125.65	2.65	In 2009, it was planned to install 2,500 MW on roofs of public buildings. Installation of 800,000 m^2 of solar panel in various places.
Canada	200	500	150.00	0.73	The country's largest plant has an installed capacity of 80 MW covering an area of 380 ha.
China	893	2,900	224.75	4.24	There were over 400 PV companies producing 23 % of the solar power hardware. Solar water heating is extensively practised.
Czech Republic	1,953	1,960	0.36	2.87	—
France	1,025	2,831	174.49	4.14	After complete exhaustion of the reserves, the 250 years old coal mining had come to a stop in 2004. France is now developing solar power to supplement its nuclear power.
Germany	17,320	24,875	43.62	36.36	Germany has an ambitious plan to replace its nuclear power mostly by solar power by 2022.
Greece	206	631	206.31	0.92	Small PV farms exist throughout the country.
India	189	450	138.10	0.66	A large project is proposed in 35,000 km^2 of area in Thar desert which will be sufficient to produce 700–2,100 GW and another in Jabalpur district of Madhya Pradesh. The Government has selected 60 cities to develop as 'model solar cities' and promote use of solar water heaters and rooftop solar panel. There is a target to produce 20 GW by 2020.

(continued)

Table 5.2 (continued)

Country	PV power capacity (MW) 2010	2011	Growth (%)	% share in the world during 2011	Remarks
Italy	3,502	12,764	264.48	18.66	At the end of 2010, there were 155,977 solar PV plants and the total energy production was about 1906 GWH.
Japan	3,617	4,700	29.94	6.87	After the Fukushima Daiichi nuclear plant accident in 2011, the Government has decided to phase out nuclear power by 2030 and increase its renewable power capacity to make good the shortfall (it is dependent on other sources of energy like coal and natural gas). Japan is also a top supplier of hardware.
Slovakia	145	488	236.55	0.71	–
Spain	3,892	4,214	8.27	6.16	It is one of the European countries with abundant sunshine and an advanced country in solar energy development.
UK	72	1,014	1,308.33	1.48	The second tallest building in Manchester, the CIS tower was clad in PV panels at a cost of £ 5.5 million and started feeding electricity to the national grid in November, 2005. Till 2011, the tariff subsidy was high so as to serve as an incentive to solar power industry but in August, 2011 the subsidy was drastically reduced for installations over 50 KW.
USA	2,519	4,200	66.73	6.14	There is considerable activity and the largest PV installation in the world is in California with a capacity of 354 MW. Rooftop installations are being encouraged.
Others	2,938	3,871	31.76	5.66	These countries include Portugal, Austria, Switzerland, Netherlands, Israel, Slovenia, Luxembourg, Bulgaria, Sweden, Finland, Denmark, Cyprus and Ukraine each of which had installed capacities ranging from 10–190 MW in 2011. There was no African country.

Source: Wikipedia: Solar Power by Country; www.google.com, 2012

intrinsic cost of solar electricity is still much higher than the retail price of power from conventional sources (Swaminathan 2007). Solar power costs Rs 9–10 per unit in rooftop PV panels. Though the cost of power generated in pilot CSP (or CST) projects in US and Spain is estimated to translate into Rs 5 per unit in India, such plants consume huge quantities of water for cooling towers and hence will be inappropriate in areas of water scarcity (Swaminathan 2010).

(d) *Natural factors:* Solar power depends on abundant and uninterrupted sunshine for its efficacy. Not all countries and not all areas of a country can, therefore, be suitable for installation of solar panels.

However, in spite of the above disadvantages, growth of the solar power industry has been phenomenal because of the following factors.

(a) Global warming is now a worldwide concern thanks to the campaign of the environmentalists supported by the scientists, UN and other institutions and the governmental initiative starting from Kyoto Protocol in 1997 to Rio-2020 in 2012. Solar energy is totally pollution-free and it has great potentiality to earn carbon credits (Swaminathan 2007).
(b) Every government is promoting development of this industry through liberal subsidies in its eagerness to show to the world that it is doing a lot to reduce greenhouse gas emission. (Swaminathan 2007).
(c) It is now recognized that solar power would increasingly supplement conventional energy in fulfillment of growing energy demand.

The future outlook is gradually undergoing a change. The emerging trends are as follows.

(a) *Solar thermo-photovoltaic:* Some scientists of the Massachusetts Institute of Technology have invented a novel way to concentrate sun's rays without using mirrors as reported in the journal *Nanoscale Research Letters* in 2011. The devise developed is called solar thermo-photovoltaic (solar TPV) which uses what is called 'photonic crystal'. This crystal prevented the absorbed heat from escaping thereby achieving very high temperature without using costly mirrors. This may be a more cost-effective substitute of CSP (*Hitavada,* Dec 8, 2011).
(b) *Sun Believable Solar Paint:* As reported in the journal *ACS Nano* published by the American Chemical Society in 2011, researches in the Centre for Nanoscience and Technology, Notre Dame have led to the invention of an inexpensive solar paint christened as 'Sun Believable Solar Paint'. By introducing power-producing nano-particles called 'quantum dots' into a spreadable compound converting the latter to one-coat solar paint. This paint is based on nanosized particles of TiO_2 coated with either cadmium sulphide or cadmium selenide. When a coat of this paint is applied on a conducting surface and exposed to sunlight, it creates electricity thus turning the painted surface to solar cells (*Hitavada*, Dec 23, 2011).
(c) *Copper-indium diselenide (CIS) solar panels:* A project under the aegis of the European Commission is aimed to develop photovoltaic roof tiles and overhead glazing facade elements based on CIS materials incorporating therein architectural and aesthetic aspects (European Commission 2005).
(d) *Off-grid solar:* The solar mission of the Government of India has envisaged off-grid applications reaching 2,000 MW by 2022. Such applications would include remote village electrification, irrigation pump sets, telecom towers, back-up

power generation, city street lighting, billboard lighting etc. In India, huge quantities of imported kerosene are consumed for lighting rural homes and this is expected to be significantly substituted by off-grid solar electricity. The current model proposes a combination of subsidy and low-interest loans for promoting off-grid applications (*Hitavada,* July 14, 2010).

5.2.2 Wind Energy

The economic use of wind energy dates back to the prehistorical times between 8000 and 5000 BC when the technique of preparing linen cloth was invented followed by its application in sailing boats to cross oceans. During the historical times till the mass usage of electricity in the late nineteenth century, wind mills for grinding wheat to flour, for pumping seawater for salt-making etc. were common. The earliest evidence of converting wind energy into electricity for lighting dates back to 1887 when a Scottish academic namely James Blyth built a cloth-sailed wind turbine in the garden of his cottage to charge accumulators which he used to power the lights in his cottage. The technology of modern utility-scale horizontal wind power turbines was first developed in US in 1975 and this paved the way for turbines of today which are capable of delivering 7 MW. The estimations of total economically extractable wind energy vary from 18 to 170 TW. Power generation usually comes from winds very close to the surface of the Earth, but winds at high altitudes are stronger and more consistent in speed.

Commercial electricity from wind power is now-a-days generated in wind farms which may consist of up to several hundreds of wind turbine towers covering an extensive area of up to hundreds of square kilometres. But the effective land area occupied by all the towers is small because the areas between the towers may be used for agriculture or other purposes. Individual turbines in a wind farm are interconnected by a power collection system which is then connected to the grid through a transformer. As of 2012, the two largest onshore operational wind farms were in US having capacities of 1,012 MW and 781.5 MW while the farms in UK (300 MW) and Denmark (209 MW) are the largest offshore (status as of 2010). As of 2011, there were 83 countries in the world using wind power on a commercial basis. The capacities and actual production of wind power in different countries are shown in Table 5.3.

According to World Energy Council, the annual market for wind energy has been increasing at an annual rate of 37 % and it has become one of the important players in the energy market. It is the most important bait for the German Government in its decision to close down all nuclear plants by 2022.

The main advantages of wind power are as follows.

(a) *Land use:* Although a wind farm requires on an average a relatively large area of 13.35 ha, it does not interfere with the other land uses like agriculture, park etc.

Table 5.3 Capacities and production of wind power in the world

Country	Estimated wind power capacity at the end of 2011		Wind electricity production in 2010	
	Capacity (MW)	% share in world total	Production (TWH)	% share in world total
China	62,733	26.3	55.5	15.9
United States	46,919	19.7	95.2	27.2
Germany	29,060	12.2	36.5	10.6
Spain	21,674	9.1	43.7	12.7
India	16,084	6.7	20.6	6.0
France	6,800	2.8	9.7	2.8
Italy	6,747	2.8	8.4	2.5
UK	6,540	2.7	10.2	3.0
Canada	6,540	2.7	8.0	2.3
Portugal	4,083	1.7	9.1	2.6
Others	32,446	13.8	48.5	14.1
World	238,351	100	344.8	100

Source: Global Wind Energy Council

(b) *Pollution:* It is zero-pollution power.
(c) *Energy storage and economic value:* Although the energy generation depends on speed of the wind which is variable according to the season, there are grid-energy storages which can store the energy developed during high-wind periods and the type of storage needed depends on wind penetration levels. Low penetration requires daily storage while high penetration requires storage for as long as a month or more. And this stored energy increases the economic value of wind energy because it can be shifted to substitute higher cost generation during peak demand periods.
(d) *Convenient hedge:* Wind energy can serve as a convenient hedge against unpredictable price movements.
(e) *Cost:* Wind turbines require little maintenance. In US, the cost of wind electricity per megawatt hour was estimated in 2006 to be $ 55.80 which was comparable with coal ($ 53.10) or natural gas ($ 52.50).
(f) *Off-grid wind electricity generation:* Generally small scale wind power generation systems with capacities up to 50 KW which are located in remote and isolated localities serve well households and offices. These serve the best when used in conjunction with batteries, photovoltaic panels or diesel generators. Equipments such as parking meters, traffic warning signs, street lighting and wireless internet gateways can be powered conveniently by small wind turbines possibly combined with photovoltaic system that charges a small battery doing away with the need for a connection to the power grid.
(g) *Carbon credit:* Wind power systems—large and small scale—save considerable CO_2 emission and thus qualify for earning carbon credits.

On the other hand, there are a few disadvantages as under.

(a) *Offshore wind energy:* In offshore areas wind speed is high and consistent but the cost of transmission to the consumption centres is high.
(b) Environmental impact: There are reports of bird and bat mortality at wind turbines.
(c) *Raw materials:* The raw materials for the permanent magnet—one of the vital components of wind turbines—include some rare earth metals and oxides. These are praseodymium, cerium, samarium and erbium metals alloyed with cobalt and neodymium oxide. Although these rare earth metals are required in small amounts, as of 2012 they suffered from some supply problems inasmuch as 94 % of the global production is controlled by China which itself accounts for 68 % of the global consumption for various high-tech electronic products. China is curtailing supply by gradually reducing the number of mines and also the cost of production is rising because of increasing costs of controlling the pollution during treatment. Although about four to seven projects outside China were in progress in 2012, it will not be before 2016 that they will start production. Consequently, for these vital raw materials most of the countries will continue for now to be at the mercy of one country i.e. China which itself is a major consumer of them. As regards India, it depends entirely on their import because although there are abundant resources of monazite containing rare earth metals, there is no production after 2004 due to high cost of extraction. (*FIMI News*, Sept 15, 2009; March 1, 2012; June 15, 2012; Aug 15, 2012; Sept 1, 2012)
(d) *Risk in urban areas:* The rotor diameters of wind turbines are long (a 5-MW turbine requires a rotor with 120 m diameter). This may cause strong wind shear in locations near or around a group of high-rise buildings; and the wind shear may generate areas of intense turbulence especially at street level. There is therefore a high risk of mechanical or catastrophic failure associated with wind energy development in densely populated areas which in turn enormously increases the cost of insurance.
(e) *Dependence on subsidy:* Wind power generation is growing only because many countries are subsidizing installation of wind farms. This has been vindicated in 2011 when economic recession and credit crunch in US have slowed down new investments in wind power projects. According to IEA (2012), the total subsidies given by all the countries amounted to $ 88 billion in 2011 and the future holds a bright prospect of $ 240 billion total subsidy. But this all the more underscores the overdependence of wind power industry on subsidy.
(f) *Reliability and intermittency vis-a-vis grid integration:* It is now generally accepted that the level of wind power capacity in a grid cannot exceed 10 % without the grid operator incurring costs to deal with the intermittency issues. Consequently, wind power has to be balanced by flexible generation elsewhere in the system (WCI 2006).

The Global Wind Energy Council or GWEC (2009) projected that 25 % of India's energy requirements would be met by onshore wind power by 2030; and if offshore potentiality is fully harnessed that would fulfill much more of the demand.

Besides, according to GWEC, around 5 billion tonnes of CO_2 emission would be cumulatively reduced during the period until 2030. The Council in 2012 has projected the installed wind turbine capacity in the world to more than double from its 2011 level to 493 GW in 2016.

5.2.3 Bio-fuel (Biomass)

Bio-fuel includes all the waste materials from living organisms—plants and animals. It comprises a wide range of household and industrial wastes as well as the energy crops—edible and inedible, which can be converted to usable fuel. These have become important energy sources in developing and developed countries such as US, Australia, India etc. This fuel can be used for both power generation and transportation. According to IEA (2008a, b), the rate of biomass-based electricity generation in the world was 257 TWh/year in 2007 while the quantities of direct heat generated by combustion technology and by combined heat and power cycle were 4.5 EJ (or 105 tonne-oil-equivalent) and 2–3 EJ (or 47–70 tonne-oil-equivalent) respectively. The popular as well as potential ingredients include the following.

(i) Agricultural/field/plantation biomass: There are three kinds:

- Residues left after each harvesting cycle (paddy and wheat straw, corn stover etc.)
- By-products of agro-processing (rice husks, bagasse, molasses, coconut shells, groundnut shells, maize cobs, potato wastes, coffee wastes etc.)
- Energy crops (jatropha, karanj, corn, grass, hybrid poplar, hybrid willow, switchgrass, oil palm, sorghum, hemp etc. which are specially cultivated for their value as sources of energy)

(ii) *Industrial biomass:* These comprise waste materials like distillery effluents, textile wastes, black liqueur (waste from the processes of the pulp, paper and paperboard industry) etc.

(iii) *Urban waste biomass:* These are constituted by pellets, construction wastes, demolition debris, mill residues, city refuse, sewage, waste paper, used plastic objects etc.

(iv) *Forest biomass:* The natural or anthropogenic waste material left in situ in forests. Examples are rough rotten salvageable deadwood, excess small pole trees, twigs, yard clippings etc. left as residues after timber harvesting and logging.

(v) *Aquatic biomass:* Examples are algae, marine plants.

(vi) *Animal biomass:* This consists of animal dung, human excreta, rejected parts of livestock etc.

Rotting biomass from agricultural, forestry and urban sources releases methane gas which can be harnessed as useful energy. The oil extracted from the energy crops can be converted to transportation fuels like biodiesel and ethanol. Other types of biomass can be used for electricity generation.

Molasses which is a waste product from sugar industry yields highly combustible ethyl alcohol (also called alcohol or ethanol) on fermentation. This ethanol is added to gasoline as a partial substitute in US and Brazil and other countries where petroleum is very costly and where molasses is available in plenty. Ethanol can also be produced from maize but the energy balance (i.e. the ratio of energy content in ethanol to the energy needed to produce it) is only 1.3 compared to 8.3 of the ethanol produced from sugarcane (Swaminathan 2007).

The energy crop jatropha (*Jatropha curcas*) is an inedible (for both humans and animals) plant and is a potential bio-fuel. It is easily grown in dry waste land. Its life is about 50 years and it can yield up to five tonnes of oil seeds per hectare. This plant contains 25–35 % of oil which can be converted to biodiesel. The residue left after oil extraction is a useful raw material for soap, candle, glycerin and compost. This biodiesel is carbon neutral and its use qualifies to earn carbon credits. In 2006, the cost of extraction of biodiesel from jatropha in India was estimated to be Rs 20/litre.

The technologies for energy recovery from biomass involve combustion, gasification, pyrolysis and biochemistry (anaerobic digestion, fermentation and transesterification). Each technology is unique so as to produce a major calorific end-product and a mixture of by-products. Versatility of modern biomass technologies to use a variety of biomass feedstock has enhanced the supply potential. Small economic size and co-firing with other fuels have also opened up additional application as with bagasse, the final reject left after extraction of juice from sugarcane or similar plants, which is added to coal as a partial substitute for power generation. Biomass integrated gasifier/combined cycle (BIG/CC) technology has potential to be competitive in comparison to coal for power generation since biomass has low sulphur content. For electricity generation the most competitive technologies are direct combustion and gasification. Typical plant sizes range from 0.1 to 50.0 MW. But combined cycle applications using steam cycle followed by direct driving of turbines (cf. Natural gas discussed earlier in the chapter) have potential to generate upto 40 MW at upto 42 % efficiency (Shukla 1998).

As regards the status of development of biomass-based energy, the developments in US, China, India and Sweden (a country where biomass plays an important role in its energy perspective) are discussed as follows.

(a) *United States*

The total availability of biomass was estimated in 2002 to be 590 million wet tonnes per year which was equivalent to 3 GW of power. Of this, 20 million wet tonnes were available at prices $1.25/mega-calories or less (cf. price of coal in US in 2001 was $ 1.23). The on-grid biomass capacity as in 2011 was 11,000 MW which accounted for 1.4 % of the total electricity supply. It has been projected that by 2020, a total of 15.3 billion KWh of electricity (0.3 % of the total projected for that year) will be based on biomass (US Energy Information Administration 2002). In US, ethanol is produced from maize.

(b) *China*

China has focused on (i) a process for converting a high-quality Chinese sorghum breed into liquid fuel and (ii) pyrolysis and gasification of agricultural residue and wood. In early 1980s, it has initiated a nationwide programme to disseminate improved cooking stoves and biogas technologies leading to improvement of energy efficiency of cooking stoves to 20 % and saving of 1 tonne of wood per household. Biomass-based electricity generation penetrated the Chinese markets in the 1990s with establishment of a total capacity of 806 MW in the sugarcane-producing provinces of Guangdong and Guangxi (Shukla 1998).

(c) *India*

Biomass plays a vital role especially in rural households as a source of direct heat. As regards electricity generation, the potential based on the agricultural wastes alone has been estimated to be about 17,000 MW (Periaswamy 2011); but the estimations made by the Ministry of New and Renewable Energy (MNRE), Government of India based on different parameters varies from 18,000 to 50,000 MW and an additional 5000 MW based on bagasse generated in 550 sugar mills. The MNRE has estimated that the production of biomass (agro and forest residues) in India is in the range of 400–500 million tonnes per year and it contributes to 32 % of all primary energy used here. The Government has made it mandatory to blend petroleum with 5 % ethanol in some of the states. However the emphasis is on biodiesel production based on plants like jatropha, neem and mahua. According to MNRE, the total area of waste land in India is 63 million hectares out of which 40 million hectares can be developed for undertaking jatropha plantation, and the Government planned to plant jatropha in a total area of 11.2 ha by the end of 2012. Indian Railways have planted 15 million jatropha saplings on railway land for eventually using the biodiesel as a partial substitute of conventional diesel. In India, bagasse is used to run power generation units. In 2006, the potential in cogeneration by all the sugar industries as existing then in India was estimated to be 1,200 MW. The MNRE grants financial assistance on some kinds of projects. The status of biomass energy utilization in India in 1999 and 2003 is shown in Table 5.4.

Research has been going on for developing a new technology to make ‘cellulosic ethanol’ from not just cane juice but also bagasse and tall grasses which can be grown on submerged waste land.

(d) *Sweden*

Swedish Energy Agency has set a long-term goal to promote the use of biomass energy not only in homes but also to fuel power plant and its strategy is centred on chips and pellets made out of extensive and fast-growing willows. A pilot plant project of a consortium called “CHRISGAS” led by the Swedish Biomass gasification Centre started in 2004 was based on an integrated gasification combined cycle (IGCC) to provide both heat and power. A clean hydrogen-rich gas has been produced by steam/oxygen gasification of biomass followed by hot gas cleaning to remove particulates and steam reforming of tar and light hydrocarbons. This gas

Table 5.4 Status of biomass energy utilization in India (1999 and 2003)

Oct. 12, 1999	Oct. 12, 2003
171	571
Target for 2020: Generation of 10 GW biomass-based electricity	

Source: MNRE: Jl. Biomass Energy in India, no. 7 (Jan.–Mar.), 2011

holds promise for production of vehicle fuel on industrial scale. This gas can even be upgraded to commercial quality hydrogen for use in fuel cells discussed later in this chapter (European Commission 2005).

Some other Asian countries like Philippines, Thailand, Indonesia and Malaysia hold promise of development of biomass energy. The potential in Thailand is centred on bagasse and wastes from chemical, agro-processing and textile industries while that in Indonesia on the wastes from the plywood plants and the saw mills (Shukla 1998). A project was started in Western Australia in 2003 to produce heat and finally electricity from the stumps, leaves and twigs of pine trees after cutting them for veneer production (Chatterjee 2006).

The main obstacles of unbridled generation of biomass energy are as follows.

(a) *Land-intensiveness:* Cultivation of plants dedicated to only biomass energy (e.g., jatropha, corn etc.) is highly land-intensive; areas varying from 80 to 240 ha are required for creation of each megawatt capacity of electricity generation (cf. 2–4 ha in case of solar PV panels).
(b) *Clash between land-uses:* Use of cultivable crop land only for energy crop plantation remains controversial under 'food versus fuel' debate. One of the reasons for tripling of the international prices of wheat, rice and corn in 2009 was the diversion of about 20 % of the corn grown in the US to bio-fuel production.
(c) *Fear of water scarcity:* Cultivation of sugarcane only for producing ethanol has been questioned by many stakeholders because this crop being a water guzzler may result in severe water scarcity in the surrounding areas.
(d) *Environmental impact of forest-based biomass:* Some environmental organizations like Greenpeace have become vocal against forest-based biomass because there would be a tendency towards whole-tree harvesting which would be difficult to control. This would remove more nutrients and soil cover than regular harvesting and could be harmful to the long-term health of a forest. They also argue that it can take many decades for the carbon released by burning biomass to be recaptured by re-growing the destroyed trees (see also 'wood pellet' later in this chapter).
(e) *Biomass from forest-based industries and deforestation:* Unregulated use of the biomass like the rejects in sawmills and other forest-based industries may trigger runaway deforestation which is not allowed under the law in India.
(f) *Dependence on monsoon:* In the tropical countries like India, production of agricultural biomass depends heavily on the vagaries of monsoon (Shah 2011).

(g) *Lack of awareness amongst farmers:* For Indian farmers, cultivation of jatropha is a new venture and they lack in adequate education to appreciate its utility. Moreover, in absence of a minimum support price (like cotton, wheat etc.) and without any assured market or long term purchase contracts, they feel wary of taking up its cultivation.

(h) *Poor market penetration:* Biomass in India is looked upon as a traditional highly polluting rural fuel (cf. firewood) and is not, therefore, traded as a commercial commodity.

(i) *Availability and price of ethanol:* In India, the Union Government sets the policy regarding ethanol blending, but the state governments control the movement of molasses across interstate boundaries. Often, the latter impose restrictions and also levy taxes on potable alcohol sales.

(j) *Fodder versus biomass:* Agricultural and agro-industry wastes are fodders for cattle and other livestock.

(k) *Governmental policies:* Until the early 1990s, the policies of the Government of India were oriented towards technology push rather than towards market pull. It is only after the economic liberalization in the 1990s, a shift in the perspective to allow a greater role by the forces of market has been initiated, but the response of the market is still not enough.

(l) *Competition with fossil fuels:* The cost of externalities on account of environmental pollution associated with burning of the fossil fuels is not taken into account by the industries and the governments also do not insist on that. This is more so in India because the electricity generation, transmission and distribution services are mostly in the public sector and the tariff rates of coal-based power are heavily tilted in favour of the common consuming mass. This exclusion of the costs of the externalities amounts to implicit incentive to fossil fuels to the disadvantage of biomass energy.

(m) *Cost of biomass:* It is necessary to locate the biomass-based power plants at or near the source of the biomass because, otherwise, the cost of transportation of the latter would far outstrip its price. This restriction with regard to location of a power plant may create some other problems because they would need not only water but also other kinds of fuel like coal for blending; besides, if the power consumption centre is far away then long transmission wires would be necessary which again entail transmission losses.

In spite of the above obstacles, there is a growing realization that modern biomass technologies can reduce the wastage of energy from 66 % in case of the traditional biomass (firewood) to only 25 %. Besides, the modern biomass systems comprising some of the energy crops are carbon-neutral because they have a one-year life cycle meaning that the carbon emissions get captured by the root biomass of the destroyed crops within one year following the emissions. Hence biomass energy utilization is growing in a number of countries—particularly the developed ones.

In the present perspective of the Government of India, biomass is viewed as a competitive energy resource which can be pulled through energy markets. Under this view, the Government's role is not to push programmes, but to enact policies which internalize social benefits and costs of competitive fuels. This shift in perspective towards market-based incentives has coincided with the development of several advanced biomass technologies. This has resulted in its growth in India in the recent times. In 2008, a 17.5 KW jatropha-based power plant was successfully commissioned to supply 24 h electricity to a remote village (Ranidhera) in the state of Chhattisgarh (TOI, New Delhi, 2008).

5.2.4 Geothermal Energy

Geothermal energy indicates the heat generated deep inside the Earth due to fission of radioactive materials in the Earth's core and the rocks at some places become so hot that the deep water bodies are converted to steam. When this steam comes out in the form of hot springs, geothermal power is produced. It is one of the rare forms of energy which is neither directly nor indirectly connected with solar energy. For harnessing this energy, the technology essentially involves drilling two deep boreholes and pumping cold water through one of them causing the steam to come forth through the other.

Geothermal energy can be used as a source of electricity as well as direct heat for cooking and home-heating. The advantages of geothermal energy are as under.

(a) Environmental friendliness (CO_2 emission is on an average 400 kg per MWH of electricity which is a miniscule fraction of that in power plants based on fossil fuels; and this emission can be sequestered)
(b) Zero contamination from toxic chemicals (in modern practice, the geothermal fluids are injected back into the Earth to stimulate production, but along with them the toxic chemicals like the salts of mercury, arsenic, boron and antimony also go back into the Earth thus preventing them from causing any damage)
(c) Zero wastage
(d) Low maintenance cost
(e) Requirement of small areas of land
(f) Independence of weather conditions
(g) Sustainability of geothermal power because the heat extraction is small compared to the Earth's heat content
(h) Minimal land requirement of 404 m^2/GWh (cf. 3,635 m^2 for a coal facility and 1,335 m^2 for a wind farm)
(i) Minimal freshwater requirement of only 20 l/MWh (cf. over 1,000 l/MWh by coal-based or nuclear electricity generation)

However, it suffers from some disadvantages also as follows.

(a) Location-specificity like mines
(b) Limited number of potential sites
(c) Sites being usually far away from consuming market

(d) High cost of drilling deep boreholes including that of transporting drilling rigs often to remote sites
(e) High capital cost of installation of steam power plant
(f) Unpredictability of the amount of electricity that would eventually be generated
(g) Possibility of emission of poisonous gases at some rare sites
(h) Possibility of seismic disturbance leading to earthquakes caused by digging of deep holes and hydraulic fracturing in enhanced geothermal systems (disturbances of magnitude up to 3.4 on Richter scale have been measured)
(i) Requirement of considerable energy to pump in cold water and pump out steam
(j) Quick depletion of hot water resource in some local areas despite the overall large resources in the crust.

The following technologies are deployed to generate electricity from geothermal sources.

(a) *Dry steam technology:* This is the oldest and the simplest technology. Power plants based on this technology directly use geothermal steam of at least 150 °C temperature to drive turbines.
(b) *Flash steam technology:* This is the most common technology used today. The power plants pull deep high-pressure hot water into lower-pressure tanks. Due to the sudden drop in pressure, a flash of steam is released which is used to drive turbines. The fluid temperature must be at least 180 °C and such high temperature fluid can only come from very deep underground.
(c) *Binary cycle technology:* This is the most recent technology having been first demonstrated in Russia in 1967 and introduced in US in 1981. Power plants based on this technology can accept fluid temperature as low as 57 °C. The moderately hot geothermal water is used to flash vaporize another fluid of even lower boiling point which then drives the turbines. This is the most common type of geothermal electricity plants today. The second fluid can be some low-boiling hydrocarbon like pentane, isobutylene and propane. The efficiency of such plants is generally low—10–13 %.
(d) *Hot dry rock (or Enhanced geothermal) steam extraction technology:* This technology is suited to ground that is hot but dry or where water pressure is inadequate. In such conditions, injected fluid can stimulate production. This involves drilling of two boreholes into the steam reservoir rock and fracturing of the rock in between them with the help of explosives or high pressure water. Then water or liquefied CO_2 is pumped through one of the boreholes and it comes up through the other as a hot gas which is then used for driving turbines. This technology is actually being used in France and Germany and is under development in a few other countries.

Geothermal electricity and heat potential and actual electricity production as estimated by the International Geothermal Association (IGA) in 2000–2001 in the different continents are shown in Table 5.5.

Table 5.5 Geothermal energy potential and actual electricity production in the world (2000)

Continent	High temperature potential suitable for electricity generation (trillion watt hour/year)	Actual electricity production (gigawatt hour/year)	Low temperature potential suitable for direct heat production (exajoule/year)
Europe	3,700	5,745	≥370
Asia	5,900	17,501	≥320
North America	2,700	23,342	≥120
South America	5,600		≥240
Africa	2,400	396	≥240
Oceania	2,100	49,261	≥110
World	22,400	96,245	≥1,400

Source: IGA, March 28, 2001

Table 5.6 shows the country-wise growth of the installed geothermal electric capacity during 2007–2010.

The dependency on geothermal energy for meeting electricity demand is very high in Iceland, Philippines and El Salvador and is moderately high in the countries of Costa Rica, Kenya, Nicaragua and New Zealand. But growth rate is not high in majority of these countries except Iceland, New Zealand and Kenya. Incidentally, the country registering the phenomenally high growth rate of about 50 % i.e. Turkey was not much dependent on this form of energy in 2010. On the other hand, it has been projected that Indonesia, which was having the third largest installed capacity in the world and where the growth was moderate in 2010, could become a superpower country in electricity production from geothermal energy (Al Gore 2011).

In US, which is the leading country in geothermal electricity production capacity, there are 77 power plants. The largest group in the world is The Geysers (active installed capacity 1,517 MW) which is located in Mayacamas Mountains in northern California and its 22 plants are spread over an area of 70 km^2; the steam comes from over 350 wells drilled into the reservoir in greywacke sandstone and the primary source of the steam is a large magma chamber at a depth of 7 km and having diameter of over 14 km; here micro-seismic events of intensity 0.5–3.0 on Richter scale have been caused due to drilling. Other notable geothermal fields under harness are (i) Cerro Prieto, Mexico (620 MW), (ii) Larderello, Italy (547 MW) and (iii) Wairakei, New Zealand (216 MW). Although, there is great potential in the Canadian Cordillera (estimations vary from 1,550 to 5,000 MW), this source of electricity has not been developed until 2010 (IGA 2011).

Geothermal fields are closely associated with volcanic and tectonic activities. At present, the maximum depth of the geothermal wells is 3 km, beyond which the cost becomes prohibitive. However, geothermal resources have been prognosticated up to a depth of 10 km. Technological research is now directed towards drilling wide boreholes at low cost and to break larger volumes of rock.

Table 5.6 Installed online geothermal electric capacity in the world

Country	Online geothermal electricity generation capacity (MW)		Average annual growth during 2007–2010 (%)	Share in total electricity production in 2010 (%)
	2007	2010		
United States	2,687	3,086	4.61	0.3
Philippines	1,970	1,904	−1.12	27.0
Indonesia	992	1,197	6.89	3.7
Mexico	953	958	0.17	3.0
Italy	811	843	1.32	1.5
New Zealand	472	628	11.02	10.0
Iceland	421	575	12.19	30.0
Japan	535	536	0.06	0.1
El Salvador	204	204	Nil	25.0
Kenya	129	167	9.82	11.2
Costa Rica	163	166	0.61	14.0
Turkey	38	94	49.12	0.3
Nicaragua	87	88	0.38	10.0
Russia	79	82	1.27	–
China	28	24	−4.76	–
France	15	16	2.22	–
Germany	8	7	−4.17	–
Others	140	147	1.19	–
World	9,732	10,722	3.39	–

Source: IGA (2011)
Note: 'Others' consists of seven countries namely Papua New Guinea, Guatemala, Portugal, Ethiopia, Austria, Australia and Thailand; capacity varies from 0.3 MW in Thailand to 56.0 MW in PNG during both the years

Insofar as India is concerned, commercial harnessing of geothermal energy is insignificant although there have been some experiments going on. The geologically potential belts are as under.

(a) Himalayan Province: Tertiary orogenic belt with Tertiary magmatism
(b) Areas of faulted blocks: Aravalli belt, Naga-Lushi, west coast regions
(c) Volcanic arc: Andaman-Nicobar arc
(d) Deep sedimentary basin of Tertiary age such as Cambay basin in Gujarat
(e) Radioactive Province: Surajkund (Haryana), Hazaribag (Jharkhand)
(f) Cratonic Province: Peninsular India

There are about 340 hot springs, but they are not of very high temperature and discharge. During oil and gas well drilling high subsurface temperature, thermal fluids and steam blow-outs have been encountered at depths ranging from 1.5 to 3.4 km. Till December, 2011, the following six most promising geothermal sites have been identified.

1. Tattapani (Chhattisgarh)
2. Puga (Jammu and Kashmir)
3. Cambay Graben (Gujarat)
4. Manikaran (Himachal Pradesh)
5. Surajkund (Haryana)
6. Chhumathang (Jammu and Kashmir)

There is a plan to set up the first geothermal power plant with 2–5 MW capacity at Puga valley in Jammu and Kashmir.

5.2.5 Hydrogen

Hydrogen being the lightest of all substances tends to escape into the space and only the hydrogen in the form of some compound like water, hydrocarbons, hydrates etc. are found in the Earth. Its melting point is −259 °C and boiling point −253 °C, at all temperatures above which the cryogenic hydrogen will flash. This property makes it a highly explosive substance capable of releasing intensive energy. It is actually not an energy substance but an energy-carrier which moves and delivers energy in a usable form to consumers (cf. electricity).

Since mining of hydrogen from its unlimited resource pervading the space is not in the realm of possibility in the immediate future, the only option for tapping this energy source is to dissociate it from its compounds, most common amongst which are hydrocarbons and water. Biomass has also been receiving considerable attention (see 'Bio-fuel' discussed earlier in this chapter).

Zero pollution effect is the principal advantage of hydrogen, the product of its burning being water. Hydrogen economy will depend on how economically hydrogen can be produced on industrial scale. There are two technologies of its production as under.

(a) *Electrolysis:* Electricity is run through water to separate the hydrogen from the oxygen atoms. However, if the electricity is sourced to fossil fuels, then the zero-pollution advantage of hydrogen is lost to a large extent. Hence obtaining hydrogen from this method by using biomass, wind or solar energy for the required electricity is being studied as a viable low-cost and carbon-neutral option.
(b) *Reforming:* In this method hydrogen is extracted from methane, natural gas and other hydrocarbons by application of heat. However, it is attended with generation of the greenhouse gases CO_2 and CO.

Nevertheless, in both the processes, more energy is required than can be retrieved from the gas later on. Now-a-days the ability of some algae and bacteria, which give off hydrogen under certain conditions by using sunlight as their energy source, is receiving attention.

Liquid hydrogen has been used in launching rockets. Now research is underway in several countries such as Japan, US, Germany and India to make it a suitable fuel for running transport vehicles. The most formidable problem is its susceptibility to flash and explosion in ambient conditions which makes it risky to carry in tanks or cylinders. Research efforts are therefore directed to development of some special alloy which will absorb hydrogen, store it and later on release it slowly as per need. Even then, its use as an aviation fuel may not be possible because of the possibility of the exhaust steam instantaneously freezing to ice at high altitude. A technology is being tested to combine hydrogen with CO_2 extracted from the exhaust gases of coal- and gas-fired power plants or from the air directly to make a synthetic octane fuel suitable for use in vehicles (Dyer 2008).

In India, research, development and demonstration efforts are directed towards bridging the technological gaps in different areas of hydrogen energy including its production, storage, transportation, delivery and safety codes and standards. An ambitious programme has been drawn to produce one million hydrogen-fueled vehicles and 1,000 MW aggregate hydrogen-based power generation.

Hydrogen can also be converted to electricity in a fuel cell (see below).

5.2.6 Fuel Cell

A fuel cell combines hydrogen and oxygen to produce electricity, heat and water by converting electrochemical energy into electricity. It operates best on pure hydrogen but some of them can be fuelled directly with methanol. A catalyst splits the hydrogen molecules into electrons and protons. The protons pass through an electrolyte membrane, while the electrons create an electric current. The electrons and protons are then re-united and combined with oxygen to create water.

A fuel cell generates a tiny amount of direct current (DC) electricity. So in practice, many fuel cells are assembled into a stack and the DC output must be routed through a conversion device called inverter. A fuel cell contains an electrolyte which must allow the ions of hydrogen or oxygen to pass through. As long as a supply of hydrogen and oxygen is maintained, electricity will be generated. The electrolyte, the material of the electrodes and the type of fuel are the key to the efficiency of a fuel cell. Some fuel cells need pure hydrogen and need a reformer to purify it; some others can tolerate some impurities but need higher temperature for running efficiently; in others using liquid electrolytes, the latter has to be circulated and will need pumps. Several types of fuel cell technology are in various stages of development. Their names are after the electrolyte used as under.

1. *Phosphoric acid fuel cell (PAFC):* Efficiency ranges from 40 to 80 % and the operating temperature from 150 to 200 °C. Output achieved so far is 200 KW, but tested up to 11 MW. Platinum electrodes are used which double up as catalysts. The fuel can tolerate up to 1.5 % CO and hence there is some flexibility in the choice of fuel.

2. *Molten carbonate fuel cell (MCFC):* The electrolyte is composed of sodium, magnesium, potassium or lithium carbonate and the temperature has to be high enough to maintain it in molten state, as high as 650 °C—too hot for home use. Efficiency ranges from 60 to 80 %. Units with capacity up to 2 MW have been tested. The waste heat can be recycled to generate additional electricity. Nickel electrode catalysts are used which are relatively inexpensive compared to platinum used in PAFC. Also, carbon ions are used up in the reactions and hence their continuous replenishment through injection of CO_2 is necessary.
3. *Proton exchange membrane fuel cell (PEMFC):* The fuel (i.e. metallic oxides) has to be specially purified. The electrolyte consists of a thin flexible permeable polymer sheet, but expensive platinum catalysts have to be used on both sides of the membrane. Efficiency is about 40–50 % and the operating temperature about 80 °C. Output ranges from 50 to 250 KW.
4. *Solid oxide fuel cell (SOFC):* The electrolyte is made up of a hard ceramic compound of zirconium or calcium oxides. Efficiency is about 60 % and the operating temperature up to 1,000 °C. Output ranges up to 100 KW. The advantages are that at such a high temperature tolerance of hydrocarbons being more, a reformer is not required for extracting hydrogen from the fuel and that the waste heat can be recycled to generate additional electricity.
5. *Green fuel cell:* This is only a modified version of the SOFC aimed at by a European Commission project, in which biomass gasification systems and SOFCs are combined. The broad principle involves production of a low-tar gas by means of a tar decomposition and gas-cleaning system followed by its integration with a woody biomass gasifier. (European Commission 2005)
6. *Alkaline fuel cell:* The fuel is composed of compressed hydrogen and oxygen and the hydrogen must be pure. The electrolyte is made up of an aqueous solution of KOH and expensive platinum electrode-catalysts are necessary. Efficiency is about 70 % and the operating temperature 150–200 °C. Output ranges from 0.3 to 5.0 KW.
7. *Direct methanol fuel cell (DMFC):* These require large amounts of expensive platinum catalysts and at present are not receiving serious attention.
8. *Regenerative fuel cell and hydrogen peroxide fuel cell:* At present these are not receiving serious attention.

Out of these, the phosphoric acid and the alkaline cells are already in use. The former type of cells are installed at utility power plants, hospitals, hotels, schools, office buildings and airport terminals; and the latter type is long used by the National Aeronautics and Space Administration (NASA) on Apollo space missions for both electricity and drinking water.

In India, a scientist of the NSN Research Centre for Nanotechnology and Biotechnology has developed a fuel cell that works on a nano-material developed from edible vegetable oil and has given good results on laboratory scale. The MNRE of the Government of India has given encouragement to pursue with the effort with a view to scaling up (TOI, Aug. 18, 2012).

However, the fuel cells of today are not cheap and efficient enough so as to replace the conventional power utilities. Nevertheless it is believed that fuel cells will become the norm in many applications within the first quarter of the twenty-first century—be it for transport or energy supply or in an industrial application.

5.2.7 *Fusion Power*

This refers to thermal energy generated by fusion of two light atomic nuclei with each other to form a heavier nucleus in a thermonuclear reactor. The isotopes of hydrogen namely protium, deuterium and tritium are the possible light atoms out of which the last two are currently the preferred ones—either deuterium-tritium or deuterium-deuterium fuel cycle with the isotope of helium (He-4) as the end product of fusion. These cycles are the replica of what is happening continuously inside the sun and, in a sense, it is a manifestation of solar energy.

The first human-initiated fusion reaction was demonstrated in the early 1950s when a series of test explosions of thermonuclear bombs (or hydrogen bombs) was conducted. The first fusion-based bombs released 500 times more energy than early fission bombs (atom bombs). But its civilian application, in which explosive energy production must be replaced by controlled production, is still under development. The principle consists in heating the two hydrogen isotopes to 15 million degrees Celsius resulting in a high-temperature electrically charged gas called plasma. For continuous fusion power, the plasma must be controlled, kept heated and contained using powerful magnetic fields. A 12.8 billion dollar project named the International Thermonuclear Experimental Reactor (ITER), which was first proposed in 1985, has been started in 2006 in Cadarache (southern France) by a consortium of seven participating countries named the International Fusion Energy Organization. The countries are India, China, Japan, South Korea, Russia, US and the EU.

Both deuterium and tritium can be obtained from seawater—a virtually unlimited resource (more than one atom per 10,000 hydrogen atoms has a deuterium nucleus). Moreover, the thermonuclear energy is clean and safe. As regards the question of sustaining the plasma, the maximum that has been achieved in the prototypes is 1,000 s. But the aim of the ITER is to produce 500 million watts of fusion power continuously for 10 min in the first phase and to standardize a commercial process by 2040. It is indeed going to be the most formidable scientific and engineering challenge of the twenty-first century.

There is another possibility further down the line. The helium isotope He-3 (practically nonexistent on Earth except in natural gas at a few locations) and deuterium may be a major source of nuclear fusion power, and extraction of helium-3 from the extraterrestrial sources—particularly the Moon—is considered very much within the realm of practicability. Helium-deuterium fuel cycle may emerge as a better option for producing commercial fusion power. When helium-3 combines with deuterium, the fusion reaction proceeds at a very high temperature and it can produce extremely high amounts of energy. It has been estimated that just 25 tonnes of helium, which can be transported on a space shuttle, is enough to provide electricity for the US for one full year. However, the reactor technology for converting helium-3 to energy is still in laboratory experimentation stage.

Now a technology beyond helium is looking like a possibility in the foreseeable future. Scientists of the Department of Chemistry in the University of Gothenburg have claimed to have created what is known as 'ultra-dense deuterium (UDD)' or 'heavy hydrogen' which is 100,000 times heavier than water. It may eventually prove to be a very efficient fuel in laser-driven nuclear fusion (*Hitavada,* May 31, 2009).

Another challenge is to develop a cost-effective material for building the lining of a fusion reactor. The lining will have to withstand a very high temperature within the reactor—much higher than a fission reactor.

However the overriding advantage of fusion power lies in the fact that there is no nuclear waste. And it may become a reality in the near future as far as technology is concerned, but the question of cost will still have to be addressed.

5.2.8 Methane Hydrate (or Gas Hydrate or Clathrate)

Methane hydrate (a kind of gas hydrate) is a natural clathrate in which methane is entrapped in the lattice of water-ice crystals without being chemically bound. It is formed by two processes and accordingly there are two types of methane hydrate as under.

(a) *Biogenic methane:* It is the common byproduct of bacterial ingestion of organic matter (cf. methane produced in swamps). It occurs within buried sediments all over the globe and is considered as the dominant source of the methane trapped in hydrate accumulation in shallow seafloor sediments.
(b) *Thermogenic methane:* Methane is produced by prolonged action of heat and pressure on buried organic matter and it starts migrating. When sufficient quantities of methane reach the zone of hydrate stability, it combines with water in the sediments to form methane hydrate.

When the methane is dissociated from the ice then the volume of methane under standard temperature and pressure (STP) released is 164 times that of the ice. In fact it is nothing but highly concentrated natural gas and hence much attention is being given to it as a potential source of methane for energy supply.

It is known to occur in both terrestrial and marine environments. Terrestrial deposits have been found in the polar regions hosted by the sediments within the Permafrost while the marine occurrences are mainly in the sediments of the Earth's Continental Margins. The specific conditions under which it can form and remain stable are as follows.

(a) *High pressure:* Deeper the occurrence under the ocean is, higher would be the pressure.
(b) *Low temperature:* Deeper the occurrence under the ocean is, lower would be the temperature of the water.

(c) *Sufficient availability of both methane and water:* Without this there won't be enough methane hydrate.
(d) *Existence of pores in the host sediments:* These pores are where the ice crystals containing the methane hydrate are trapped and there should be enough of them so as to accommodate the crystals. This implies that the sediments should be unconsolidated.
(e) *Low salinity of the water in the pores of the sediments hosting the methane hydrate:* High salinity lowers the ice-forming temperature making it difficult for the ice to crystallize.
(f) *Biologic productivity:* This should be high. Very deep oceans generally lack the high biologic productivity needed to create the organic matter that generates methane.
(g) *Rate of sedimentation:* This should be rapid so as to deeply bury the organic matter. Under very deep oceans the rate is generally not very rapid.

Considering all the above conditions it can be surmised that there is an optimum range of depth— neither too deep nor too shallow—which is the ideal locale for deposition of methane hydrate.

Layers of methane hydrate are found along the continental margins of the oceans at depths ranging 500–3000 m and at less than 800 m depth in terrestrial lakes; and the layers are generally 5–10 m thick. They generally contain 90 % methane. Till 2004, a total of 77 potential sites have been identified out of which methane hydrate has been actually recovered in 19 places located in the US continental margin and offshore areas of Alaska, Japanese continental margin, Lake Baikal, Messoyakha gas hydrate field in western Siberia (the only place where recovery is on a commercial scale) etc. Insofar as India is concerned, locations off the coasts of Mumbai, Goa, Mangalore and Kochi in the Arabian Sea and off the coasts of Puducherry, Chennai, Kakinada, Visakhapatnam and Paradip in the Bay of Bengal have been identified. The estimated global prognostic resource as in 2004 was over 20 quadrillion m^3 in deep offshore and 10 trillion m^3 in the Arctic regions while that in Indian offshore area was 40–120 trillion m^3 up to a depth of 2,000 m along its continental margin. The Government of India has already drawn a Rs 1-billion national gas hydrate programme in 2006 for mapping its entire gas hydrate resources through the National Institute of Ocean Technology (NIOT), Chennai; a remotely operated vessel (ROV) has already been developed which can go down to the ocean bed and remain there to map the gas hydrates and collect samples (*Hitavada,* Sept 29, 2006).

Substantial energy resources may be available from methane hydrate deposits using largely conventional drilling and production technologies as in the case of natural gas. However there are some additional processes involved in the recovery of methane from methane hydrate which are being investigated. The researches for recovering methane from gas hydrates are centred on the following technologies.

(a) *Thermal stimulation:* In this method, temperature is increased through heating so that hydrate breaks into water and gas.
(b) *Depressurization:* In this, the pressure is lowered by pumping out gas at the base of the hydrate causing dissociation of gas from water.
(c) *Inhibitor injection:* In this, a dissociating reagent (e.g. methanol) is injected into the hydrated sediments leading to release of gas from the hydrate.

All these technologies may have to be deployed simultaneously. Dissociation of gas from water is an endothermic process. So a natural consequence of dissociation is cooling and potential re-freezing of the adjacent portions of the reservoir. Therefore depressurization accompanied by local heating may also be required so as to overcome the tendency of the hydrate to return to its stable, frozen state. Methane hydrate wells will be more complex than most natural gas wells due to a number of technical challenges as follows.

(a) Maintaining commercial gas flow rates with high water production rates
(b) Operating at low temperatures and low pressures in the wellbores
(c) Controlling the loose unconsolidated sand of the host formation which will tend to enter the wells along with the gas and water
(d) Ensuring structural integrity of the well
(e) Preventing large scale landslides in the oceans caused by heating and expansion of the hydrate in and its evacuation from the pores of the unconsolidated host formation

Technologies exist to address all these issues, but their implementation will add to overall development costs for producing methane from hydrate. Besides, there is the formidable risk that any lapse may end up in mixing of huge volumes of this greenhouse gas with air causing substantial global warming. Further, exploitation from the Arctic reservoir may have additional impact on Arctic Region wildlife and plants (Ghosh 2005; Chatterjee 2010; NETL 2011).

5.2.9 Ocean Energy

There are four ways in which ocean energy can be harnessed: (a) Tidal energy, (b) Ocean Thermal Energy Conversion (OTEC), (c) Wave energy and (d) Salt gradient energy. These are as follows.

(a) *Tidal energy:* The methodology consists in channelling and storing of the tides for electricity generation mainly in the estuaries where tides are most active. In China, the first experimental tidal energy electric power station went into operation in May, 1981 in Zhejiang province in eastern China. Tidal power is generated in small quantities in France, Russia and UK. In India, a pilot research and development project was planned to generate tidal power off the coast of Ratnagiri in western coast of Maharashtra (*Hitavada*, Dec. 14, 2006).
(b) *OTEC:* The technique uses the thermal gradient in the ocean due to the difference in temperature between the warm waters at the surface and the ice-cold waters at several hundred metres depth, to generate electricity. The first unit named ‘Mini-OTEC’, was successfully operated in 1979 on a US Navy barge off Kona coast of the Hawaii island. Its generation capacity was 50 KW. From the point of view of depth of ocean and nearness to shore, the eastern coast of

India is more favourable than the western coast. Off the eastern coast, sufficiently deep waters are available within 22–54 km range, while in case of the western coast, deep waters are rather far away—beyond about 150 km. Some locations off Tamil Nadu, Andaman and Nicobar Islands and Lakshadweep have been identified as promising.

(c) *Wave energy:* This is the mechanical energy from wind retained by waves. The oscillating movement of sea waves can be transformed into electricity. In India, in the early 1990s, such a plant of 150 KW capacity was constructed 45 m in front of the break water off Vizhingam fishing harbour in Kerala.

(d) *Salt gradient energy:* This is the energy coming from salinity differences between fresh water discharges into oceans and ocean water. There is no report of any practical utilization of this potential.

Although the Law of the Sea has granted right to a coastal country to harness ocean energy within the Exclusive Economic Zone (EEZ), there is no indication at present that these technologies of energy can be of commercial significance except in oil drilling platforms.

5.2.10 Bacteria

The ability of some algae and bacteria, which give off hydrogen under certain conditions by using sunlight as their energy source, is receiving attention (already mentioned under 'Hydrogen' earlier in this chapter). The experiments are mainly in the following directions.

(a) Genetic modification of a micro-organism so that it would metabolize CO_2 and turn it into fuel. However, for continuously feeding the bacteria with CO_2, the latter would have to be separated and extracted from the air in large quantities and then concentrated (*Hitavada*, Mar. 5, 2008).

(b) A type of bacteria has been found which thrive on the cathode of an electrolytic cell, feed on the electrons and use that energy to convert CO_2 to methane. The methane can be stored and burned when needed. Of the electrical energy fed into the system 80 % would be recovered on burning the methane. This is actually a high-efficiency and low-cost energy storage system by which wind and other forms of energy can be stored for using as per need (*Hitavada*, Apr. 12, 2009).

(c) Certain type of algae has been found to be able to not only break cellulosic biomass (e.g. poplar tree) into simple sugar but also ferment it to acetate and ethanol—a bio-fuel (*Hitavada*, July 19, 2009).

(d) Bacteria-based battery is in a preliminary research stage, and is under development in US and Japan. The output is very small, but nevertheless it is being conceived as a potential supplementary source of electricity for household consumption.

However, there is no indication that this form of energy can be produced in industrial and commercial quantities so as to substitute any of the conventional fuels.

5.2.11 Industrial Waste Heat

It is now possible to capture waste heat from industrial smokestacks and turn it into electricity. The temperature of the combustion gases and the smoke being low, propane gas (C_3H_8) instead of steam has been used to drive turbines.

5.2.12 Wood and Wood Pellet

These are different from both firewood and biomass. Unlike firewood and biomass, this wood comprises intentionally cut healthy trees and their branches which are used for thermal power generation. In Poland and Finland, such wood has been accounting for 80 % of their renewable energy demand while in Germany the figure is 38 % of the total non-fossil fuel consumption.

After the EU set a target to get 20 % of its energy from renewable sources by 2020, some European countries have realized that solar and wind energy are not going to help them meet that target and wood pellet has become the newest craze in Europe. It is argued that wood pellet will be carbon-neutral because the CO_2 that billows out of the chimney can be offset by the CO_2 that is captured and stored in newly planted trees and the power stations can be adapted to burn a mixture of 90 % coal and 10 % wood pellet (one of Europe's largest coal-fired power stations namely Drax in UK is planning to convert three of its six boilers to burn wood and generate 12.5 terawatt hours of electricity a year from 2016). The British government has offered subsidy to this power plant to the extent of £ 45 ($ 68) for every MWh of electricity actually generated from wood pellet. Consequently, its consumption in Europe rose to 12 million tonnes in 2012 and the demand is predicted to rise to 25–30 million tonnes by 2020 resulting in shooting up of the price of wood in western Canada, the main supplier of hard wood to Europe.

The process involves grinding the wood, turning it into dough and then putting it under pressure. In other words, it produces CO_2 twice over—once in the power station and once in the supply chain including the manufacturing process and shipping. Besides, carbon-neutrality will depend on the type of forest used, how fast the trees grow, whether one uses wood chips or whole trees (necessary for mass production) etc. According to European Environmental Agency, if whole trees are used, increase in CO_2 emission due to replacing coal by wood pellets will be 79 % over 20 years and 49 % over 40 years, and there will be no CO_2 reduction until 100 years have passed when the replacement trees have grown up. Over and above this, the British furniture industries, particle board mills and pulp and paper factories are already feeling some adverse impact of this new development (along with the subsidy) mainly due to spurt in the price of wood (FIMI, May 1, 2013).

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Chapter 6
Energy Mix and Energy Security

Energy is not only the prime mover of industrial and economic activity but also indispensable to the advancement of civilization. Initially human energy followed by animal energy marked the advancement of the ancient humans through a few hundreds of thousands of years. But the first breakthrough came when about 31,000 years ago the humans invented the technique of making fire at will by striking one rock against another. Fire eventually helped the humans to make various tools and machines for cutting trees and for digging the earth and to diversify their energy sources. Today, we have multiple sources of energy to harness—as many as 30 in numbers—as have been discussed in the last two Chaps. (4 and 5). However all countries do not have access to all those energy sources at the same time and each one uses a permutation and combination from amongst these sources.

The energy mix model suitable for a country and its energy security are interlinked and complementary to each other. From the foregoing account it can be surmised that in the macroeconomic context, present options for fulfilling a country's energy demand are limited to coal, oil, natural gas (including methane in other forms like coal bed methane and shale gas), uranium, hydropower, solar energy, wind energy, bio-fuel and geothermal energy. The other forms of energy are either futuristic or suitable at microeconomic level.

6.1 Determinant Factors

There is no universal model of optimum energy mix for all countries. It depends on the following factors.

1. *Diversification of generation capacity*

Avoiding over-reliance on one energy source is a fundamental premise of energy security, reducing exposure to supply disruptions. A well balanced energy system,

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comprising various power generation technologies with suitable capacities, allows the advantage of each to be maximized and ensures a continuing supply to the consumers.

2. *Locally available exploitable reserve*

No mature country should normally like to depend on imported raw material when there are adequate minable reserves available within its boundaries. Minable reserve as defined in any of the modern classification systems (e.g. JORC, UNFC) implies that there is no impediment to exploitation of the reserve not only on account of factors like quantity, grade, physical characteristics, technical feasibility, economic viability etc. but also on other counts like infrastructure, environment, land status, policy and law of the land, sociological issues etc.

3. *Ease of transport*

It is not enough to have locally available energy, it must be readily available also. Thus the ease and safety with which fuels and electricity can be transported is a key driver for energy security. Oil and gas can be transported through pipelines and tankers or LNG vessels; coal can be readily transported via road, rail or ship; transmission and distribution networks must be capable of carrying electricity to the consumers and able to handle the lead demands placed upon them. Besides, the interconnection of energy systems, particularly electricity, must also be considered in terms of security. A limited connection increases the risk of supply disruption by reducing the options available to demand.

4. *Infrastructure and mine-plant transportation*

While the mine-specific infrastructural facilities like roads, electricity, water, social infrastructure etc. are taken care of in the system of mineral resource classification, availability of general facilities like roads and rail tracks from a coal mine to power plant or a oil well to refinery, and (in case of import) ports and liquid natural gas (LNG) storage facilities of adequate capacity are also of vital importance for achieving diversity of energy sources.

5. *Human skill level*

Expertise in generation technologies from different sources of energy and in delivery systems such as pipelines, electricity interconnections and transmission lines is necessary for achieving optimum energy mix.

6. *Cost and price*

Cost is with regard to not only exploitation within a country but also imported mineral. Electricity cannot be imported, so the raw materials will have to be imported. And a lot will depend on the fiscal policies of the exporting countries and, the strength of the currency of the importing country. It goes without saying that the cost should be less than the price that the consumers pay. And the price should be affordable. The provision of affordable energy to the consumers is dependent on the cost of generation, transmission and distribution. The interruption of supply networks can negatively impact prices and create economic difficulties for countries vulnerable to over-reliance on one or two energy sources. Diversity of sources can provide the necessary flexibility and alternatives in times of rise in price of one of them. If the scope of exploitation is expanded to the ocean and the space, then availability does not seem to be a problem—even in the long run. But it is the affordability which is at stake. Eventually, the consumers have to be psychologically and economically prepared to pay more.

7. *Levels of investment required*

To meet the forecast growth in global energy demand, the IEA has predicted a need for $ 16 trillion in investment. This gives an idea of the order of magnitude of funds required by any individual country depending on its energy demand growth. The availability of that fund may be a problem not only for the developing countries but also for many developed countries.

8. *Dynamics of the fiscal and other policies of the Government*

Fiscal policies include taxes and duties which are charged by the governments from time to time. Consequently, what is economically viable today may not remain so tomorrow. Same is the case with other policies which include those regarding grant and tenure of permits, conditions attached to grant, foreign direct investment (FDI) policies etc. Industries want stability of all policies so that they can make long-term investment plans professionally and scientifically.

9. *Political viability*

Along with changes in the political system in a country, its policies and laws regarding mineral exploration and mining as well as its priorities may also change. For example, the new government may decide on constructing a dam or a railway track over a mineral deposit. The political risks of investment in different countries/regions are evaluated and presented in terms of the Policy Potential Index (PPI) of the Fraser Institute, Canada and the Reform Index of the World Bank.

10. *Risk of natural hazards*

In 2009, when there was an unprecedented flood in the coal-mining region of Queensland state of Australia, there was shortage of supply of coal both in the domestic market of Australia and international market because that region fulfills most of the demand of coal within and outside Australia.

11. *Finiteness of mineral resource*

This implies that over-dependence on any single mineral for energy production is not a good proposition.

12. *Risk of man-made disruptions*

Labour strikes have often disrupted supply of vital minerals as has happened in the recent past in Canadian zinc mines and Chilean copper mines. Energy supply systems may also be vulnerable to terrorist attacks. Such risks also point against overdependence on any single source mineral.

13. *Mineral resource inventory*

Mineral resource inventory of a country is a database containing information regarding all its mineral deposits along with their reserves, resources, grades locations, geologic set-ups, physical and social infrastructures, environmental viability, land status etc. This database is dynamic in the sense that continuous exploration is adding to the list of deposits and mine production is depleting the reserves. It is useful to systemically keep track of where the balance reserve of an energy-mineral stands at any particular point of time so that advance action can be taken to prioritize and alternative sources can be developed, should any need arises. But only a very few countries maintain exhaustive mineral resource inventories; India is one of them.

14. *Geological factors*

In course of mining, as depth increases it has been seen that in many deposits the head grade declines. The combination of the two factors namely increased depth and reduced head grade tends to increase the cost of mining. Eventually the production may cease to be economically viable. In the recent times, this has been the case with India's Mosabani copper mine and Kolar gold mine and also some aging copper mines of Chile. Indeed, beyond a point human factors cease to matter and geological factors take over for deciding the sustainability of production.

15. *Amenability to substitution*

The major end uses of energy can be broadly grouped into:

Electricity generation
Direct heating
Surface transportation
Maritime transportation
Aviation

So far as electricity generation is concerned, the options are fairly wide—coal, natural gas (including methane and shale gas), uranium, hydropower, solar energy, wind energy, bio-fuel and geothermal energy. For direct heating, the range of options somewhat narrows down to coal, petroleum, natural gas, solar energy, bio-fuel, wood pellet and geothermal energy. However, for the other end uses the options are very limited. For example, in surface transportation by road, petroleum is practically indispensible though to some extent natural gas and bio-fuel are being used but these can at best be considered as supplementary sources and not substitutes; similarly, in maritime transportation, no other form of energy than petroleum and uranium is suitable; and in aviation, petroleum is the only option.

16. *Accessibility to foreign sources*

If enough domestic reserves are not available or for any reason they cannot be mined, then the options to source a country's requirements are:

(a) *Import from other countries:* For this, a country has to build and maintain congenial international relation. Any gross violation of humanitarian norms may attract imposition of international sanctions and in that situation import may not be possible. Moreover, reliance on imported fuels from a limited number of suppliers may increase the risk of adverse market influence and the risk is more where suppliers are from politically unstable countries.
(b) *Acquisition of mineral deposits in other countries:* The greatest risks are those of expropriation and resource nationalism. With change of government in the host country, policies may change drastically and either an operation may be taken over entirely or heavy taxes and conditions of value addition within the host country may be imposed. Moreover, at times of war or similar emergencies, the situation may be highly unpredictable.

It is apparent that in the event of non-availability of domestic energy source, lots of political management skill is called for. After all, international relations are about give-and-take.

17. *Environmental and ecological regulations*

These limit the availability and, when they do not, add to the costs. Due to intensive anti-coal campaign by the international and national environmental activists, coal, which is the largest contributor to greenhouse gas emission, is being projected in a way as if it is the enemy of humankind. There is a clamour for converting the coal to 'green coal' before marketing it to consumers. Technologies for such conversion are known, but the issue will again boil down to the price of coal and its affordability to the consumers. There is similar campaign against oil, uranium, hydropower and bio-fuel. So far the natural gas and the solar, wind and geothermal energies have not been at the receiving end, but it is yet to be seen whether their large scale exploitation will be free from any negativity or not.

18. *Land acquisition*

This has become the principal bane of mining ventures now-a-days. Mineral deposits are rarely located in an uninhabited and barren land and mining requires destruction of the surface of the land along with its habitation, fertility and biodiversity. In case there is any clash of economic uses of land, money may compensate the loss and displacement; but biodiversity, fertility and the psychological attachment of the humans to their lands and community-living through generations may be difficult, if not impossible, to be evaluated in terms of money.

19. *Problem of mindset*

This problem is with regard to large scale use of renewable energy, especially in India. A study by the World Institute of Sustainable Energy (WISE) has revealed that the main problem of integration of the renewable energy with the conventional energy is the consumers' (include industrialists) mindset and not technical. The consumers are so tuned to the comforts of a predictable centralized conventional model with associated network that renewable energy seems to them as an unwanted change bringing them out of their comfort zones (*Hitavada*, Dec. 29, 2012).

Worldwide, the focus of efforts is on ensuring security of oil supply for transportation and on electricity generation. The insecurity-driven scramble for oil has grown so much that countries do not hesitate to attack and fight other countries. In 1990, Iraq attacked Kuwait for taking control over an oilfield and US attacked Iraq; in the north-west part of Iraq, Kurdish people are in conflict with Iraq for control over Kirkuk oilfield.

6.2 Evolution of Energy-Mix Model

The evolution of energy-mix model for power generation in the world is shown in Table 6.1.

Certain trends emerge from the above data. No doubt the total power generation capacity based on each of the fuel types has increased, but the share of oil has decreased and that of hydropower has kept pace with the increase in the total of the world. However, it means that the brunt of increase in the capacity has been borne by natural gas, coal, nuclear and the various renewable sources. Same is the trend of increase in the total thermal energy production which includes direct heating except that more of the renewable sources have been diverted from direct heating to power generation.

In US petroleum, gas and coal shared the energy demand more or less equally. The share of different energy sources in the total demand for energy during 2008–2011 is shown in Table 6.2.

As regards India, in the total energy mix, which includes power generation, coal played a dominant role in 2010 having accounted for 53 % of the total primary energy consumption (BP 2011). This share was far greater than the other sources such as oil (30 %), natural gas (10 %), hydro (5 %), nuclear (1 %) and renewable (1 %). Considering only the power generation, the sources are mainly thermal (coal and natural gas), hydro, nuclear and renewable. Table 6.3 gives the data which will serve to bring out the trend in the energy mix.

India all along depended heavily on coal followed by mega- hydropower, but the share of coal kept on increasing at the cost of mega-hydropower until the last decade of the twentieth century. When separate records of biomass power started being maintained after 2005, its significant contribution came to light, but as earlier mentioned, geothermal energy has not found a place in India's energy mix model. All through the 40-year period, development of nuclear power kept pace with the development of overall power generation capacity. The growth of coal-based power was pronounced till the late 1980s whereafter it somewhat steadied. This pattern of growth is understandable because there is abundance of reserves of high-ash coal and also the environmental laws concerning particulate emission from power plants

Table 6.1 Evolution of energy-mix model for power generation in the world (1980–2006)

Energy source	Share of different fuel types in world energy production and power generation capacity (%)						Average annual rate of increase (%)	
	1973		1980		2006			
	Thermal energy production	Power generation capacity	Thermal energy production	Power generation capacity	Thermal energy production	Power generation capacity	Thermal energy production (1973–2006)	Power generation capacity (1980–2006)
World total	6115 Mtoe	—	—	9.48 TW	11,796 Mtoe	15.8 TW	2.82	2.56
Oil	46.10	—	—	46.20	34.40	36.33	–0.77	–0.82
Natural gas	16.00	—	—	18.99	20.50	22.85	0.85	0.78
Coal	24.50	—	—	24.68	26.00	27.03	0.19	0.37
Hydropower	1.80	—	—	6.33	2.20	6.33	0.67	Nil
Nuclear fission	0.90	—	—	2.64	6.20	5,89	17.85	4.73
Renewable	10.70	—	—	0.21	10.70	1.01	Nil	14.65

Source: (1) EIA 2008 (for data on power generation capacity); (2) IEA 2008a, b (for data on thermal energy production)

Notes:

1. Mtoe or million tonne oil equivalent is amount of energy released by burning one million tonnes of oil; it includes the energy utilized for electricity generation, direct heating and wastage during conversion of thermal energy to electricity
2. TW stands for trillion watts and it is a unit of power generation capacity; actual generation may be less depending on capacity utilization
3. Renewable energy includes geothermal, wind, solar and biomass

Table 6.2 Energy-mix model for fulfilling energy demand in US (2008–2011)

Energy source	Share in the total energy consumption (%)		
	2008	2010	2011
Petroleum	33.50	37.74	38.00
Gas	20.90	26.34	23.00
Coal	26.80	26.31	26.00
Nuclear	5.80	10.06	6.00
Hydro	2.20	9.61	6.00
Other renewable sources (solar, wind, geothermal, bio-fuel)	10.60		1.00

Source: IEA (2011)
Note: For 2010 the data pertaining to hydro and renewable energy was combined

were not enforced until the late 1980s. Lately, however, there has been a growing opposition by the environmental activists to coal-based thermal power plants due mainly to pollution and also to mega-hydropower due to problems of large scale submergence and displacement of population which explains the decline in the share of both in the total power generation. Nevertheless coal continues to be the mainstay in India's energy mix model because:

(a) Kyoto Protocol (1997) has exempted India from fixing any target for reduction of greenhouse gas emission;
(b) Coal-based power continues to be cheap here; and
(c) There is no serious enough concern on the part of both the Government and the people about the air pollution effect particularly when it implies conversion of coal to clean coal thereby increasing its cost.

But, presently, even coal is not able to cope with the increasing demand of power in India if the non-electricity energy demand is taken into account. Firstly, enforcement mechanisms of environment and land acquisition laws have become so stringent that both greenfield coal mining projects and brownfield expansion projects are being increasingly difficult. So much so that India is now depending on more and more import and is planning acquisition of coal properties in other countries. But this strategy is also fraught with problems on account of an increasing tendency of resource nationalism by other countries. Nevertheless, the land acquisition problems associated with other major sources like mega-hydro and nuclear power do not leave India with much flexibility about power source at least in the foreseeable future. Although development of the different sources of renewable energy is fraught with some problems like land, technology, inconsistency, mindset etc., this component seems to have good potentiality in India. According to the World Institute of Sustainable Energy (WISE), renewable energy integration would lead to 36.34 GW of power during the 12th and 13th Plans (2012–2021). But even this cannot fully substitute the conventional fuel types.

Table 6.3 Evolution of energy-mix model for power generation in India (1970–2010)

	Thermal		Mega-hydro		Nuclear		Renewable		Total	
Year (starting from April 1)	Power (GW)	Share in the total (%)	Power (GW)	Share in the total (%)	Power (GW)	Share in the total (%)	Power (GW)	Share in the total (%)	Power (GW)	Average annual growth with respect to previous record
1970	7.91	53.77	6.83	46.43	0.42	2.86	Not recorded and hence not factored in the total power		14.71	–
1975	11.01	54.72	8.46	42.05	0.64	3.18			20.12	7.36
1980	17.56	58.13	11.79	39.03	0.86	2.85			30.21	10.03
1985	29.97	64.08	15.47	33.08	1.33	2.84			46.77	10.96
1990	45.77	69.25	18.75	28.37	1.57	2.38			66.09	8.26
1995	60.08	72.13	20.99	25.20	2.23	2.68	No separate record; clubbed with thermal source		83.29	5.21
2000	73.61	72.43	25.15	24.75	2.86	2.81			101.63	4.40
2005	88.60	71.28	32.33	26.01	3.36	2.70			124.29	4.46
2009	100.81	63.91	36.86	23.37	4.56	2.89	15.52	9.84	157.74	6.73
2010	112.82	65.24	37.57	21.73	4.78	2.74	18.45	10.67	172.92	9.62

Source: MNRE (2012)

Notes:

1. Thermal power is based on mainly coal; only in the last decade, a little natural gas
2. Renewable power comprises micro-hydro, wind, biomass, bio-gasifier, urban/industrial waste and solar sources

6.3 Energy Security

According to Powell (2012), there are two approaches to interpret energy security—liberal and realist. Liberal interpretation calls for separation between economics and politics and seeks a market-driven quest for equilibrium between energy supply and demand. In realist interpretation, on the other hand, economics is treated as subordinate to politics; and in this, energy security is not always the direct consequence of a specific threat but rather the result of political response to a perceived threat. This realist interpretation is India's approach too and it is seeking geopolitical competition for energy resources, trade routes etc. (e.g., Central Asia to India gas pipeline, India to Myanmar land and sea route). India's energy security as defined by its Planning Commission in its energy policy document should be seen in this context.

The Planning Commission of India, in its Integrated Energy Policy (IEP) document, has defined energy security thus: "we are energy secure when we can supply lifeline energy to all our citizens irrespective of their ability to pay for it as well as meet their effective demand for safe and convenient energy to satisfy their various needs at competitive prices, at all times and with a prescribed confidence level considering shocks and disruptions that can be reasonably expected" (MGMI, July–Sept, 2011). There are two elements in this definition i.e., energy demand and price subsidy.

6.3.1 Energy Demand

The demand measured in terms of actual consumption of power or electricity by different sectors in India has been steadily increasing as can be seen from Table 6.4.

Certain trends emerge from Table 6.4. The demand of power by the industrial sector has always accounted for the lion's share in the total demand, but the rate of annual growth in demand by other sectors far outpaced that by the industrial sector. Till 1970s the growth in demand of electricity by the agricultural sector was low, but thereafter electric pumps started replacing diesel pumps for drawing groundwater and the creation of the Rural Electrification Corporation (REC) boosted demand in rural areas; moreover, agricultural production also underwent revolution due to increased use of fertilizers and modern cultivation techniques. Large scale electrification of railway tracks and usage of electric gadgets in the urban homes and extension of service to rural homes provided an impetus to growth in demand by the domestic sector and the traction and railways.

The IEA has adopted the GNP maximizing paradigm to estimate the energy demand rather than trying to estimate the least amount of energy needed to wipe out poverty and how best to meet it in a sustainable manner (MGMI, July–Sept., 2011). But according to a critique by Wahi (2010), this approach has failed to take note of

Table 6.4 Trend in consumption of electricity by different utilities in India (1970–2009)

Year (starting from April 1)	Consumption of electricity											Total amount (twh)
	Industry		Agriculture		Domestic		Commercial		Traction and railways		Others amount (twh)	
	Amount (twh)	Share in total (%)	Amount (twh)	Share in total (%)	Amount (twh)	Share in total (%)	Amount (twh)	Share in total (%)	Amount (twh)	Share in total (%)		
1970	29.6	68	4.5	10	3.8	9	2.6	6	1.4	3.2	1.9	43.7
1975	37.6	63	8.7	15	5.8	10	3.5	6	1.9	3.2	2.8	60.2
1980	48.1	58	14.5	18	9.2	11	4.7	6	2.3	2.8	3.6	82.4
1985	67.0	54	23.4	19	17.3	14	7.3	6	3.2	2.6	5.0	123.1
1990	84.2	44	50.3	26	32.0	17	11.2	6	4.1	2.2	8.6	190.4
1995	104.7	38	85.7	31	51.7	19	17.0	6	6.2	2.2	11.7	277.0
2000	107.6	34	84.7	27	75.6	24	22.5	7	8.2	2.6	17.9	316.6
2005	151.6	37	90.3	22	100.1	24	36.0	9	9.9	2.4	24.0	411.9
2008	209.5	38	109.6	20	131.7	24	54.2	10	11.4	2.1	37.6	554.0
2009	236.8	39	120.2	20	146.1	24	60.6	10	12.4	2.0	36.6	612.6
Average annual growth 1970–2009 (%)	18		66		96		57		30		47	33

Source: Based on CEA (2011)

Notes:

1. 'twh' means 'terawatt-hour'
2. All figures are rounded off

the limits of nature and has projected an increase from the 2009-level of 160 GW to 800 GW in 2031–2032 comprising

coal-based power from 2009-level of 80–400 GW;
hydropower from 2009-level of 36–150 GW; and
nuclear from 2009-level of 4.5–65 GW.

Issues such as technological advancements needed in the fields of exploration, exploitation and processing; pressure on agricultural and forest lands; increased stress on freshwater resources; displacement of people; deterioration of atmospheric pollution and impact on biodiversity have not been factored in these projections.

6.3.2 Price Subsidy

The UNESC (2002) has defined an energy subsidy as any government action that lowers the cost of energy production, raises the price received by the producers or lowers the price paid by the consumers. The different types are:

Direct financial interventions

- Transfers, grants, preferential loans and liability insurance
- Tax instruments (royalties, duties, accelerated depreciation allowance etc.)

Indirect administrative interventions

- Trade instruments (quotas, embargoes etc.)
- Energy-related services provided directly by government at less than full cost
- Regulatory controls (price controls, demand guarantees etc.)
- Publicly funded energy research and development

In India, most of the above types of subsidies are borne by the Government; particularly electricity supply to farmers is heavily subsidized. But the UNECE (2003) has also listed the harmful effects of energy subsidies as under.

Subsidies often encourage higher consumption and wastage and consequently, higher air pollution and greenhouse gas emission.
Subsidies to conventional fossil fuels undermine the competitiveness of renewable energy and discourage investments in energy efficiency.
Subsidies may tend to cheating and corruption.
The extra financial burden on the government translates into additional taxes on the people and on goods and services.

According to UNESC, subsidy should ideally be aimed at minimizing the harmful effects while maximizing the social benefits. But in developing democratic countries political considerations often tend to outweigh other considerations. However, temporary subsidies may be justified as a hedge against market failures. Subsidies are also justified to promote investments in sustainable environment-friendly renewable energy or in pollution-mitigating measures, but too heavy subsidies in UK and some other European countries have proved to be counterproductive. There, the subsidization of otherwise costly wind power generated from wind turbines (including even the offshore ones) has made the environment-friendly gas-based power companies uncompetitive forcing them to switch over to coal (FIMI, February 1, 2013).

6.3.3 Future Outlook

According to the energy outlook for 2030 projected by the British Petroleum (BP), the global energy demand will grow by approximately 40 %; emerging economies will be responsible for 96 % of energy demand growth; oil will make up 87 % of world's transport fuel; bio-fuels will make up 7 % of world's transport fuel requirements and renewable energy sources will supply 11 % of world's electricity need (MEAI, May, 2012). The outlooks for sustaining energy security evolving in different countries are shown in Table 6.5.

All forms of energy have positive and negative attributes. But given that energy demand is going to continue to rise and many challenges have to be met, it is imperative for any country to review its energy options and balance these responsibly and reliably. Constructive partnerships between energy producers, energy consumers, governments and non-government environmental activists will be essential to meet the energy demand and achieve energy security with improved environmental performance.

6.4 Scientific and Technological Innovations

Today's innovations are the seeds of tomorrow's commercial application. Recognizing the importance of innovation to energy security concerns, the Government of India has announced, in January, 2013, its Science, Technology and Innovation (STI) Policy.

In the broad sense, geoengineering involves manipulation of the world's climate to avoid catastrophic warming triggered mainly by fossil fuels for energy production. Technologies like clean development mechanism (CDM) and carbon capture and storage (CCS) for making coal environment-friendly have been discussed under "Coal" earlier in this chapter. These were in innovation stage in the late 1990s and have now come of age and moved nearer to commercial reality in many countries. But till 2012, these have not yet been introduced in India for fear of energy cost escalation and lack of serious government support. On June 20, 2011 there was a global conference to explore geoengineering options. The ideas centred around putting SO_2 into the atmosphere to reflect incoming sunlight back; spraying droplets of seawater into low-lying marine clouds to thicken them up and reflect more sunlight back; painting the world's roofs and roads white; techniques for removing CO_2 from

Table 6.5 Future outlook regarding energy security in some selected countries

Country	Energy outlook
Austria	Energy efficiency at all stages of existing facilities; focus on renewables like hydro, wind, biomass, solar PV sources; target for 2020 set at 34 % share by renewables and greenhouse gas reduction by 16 % of 1990 level (Anderson 2010).
Brazil	Present shares in total energy production of oil and ethanol (46 %), hydro (39 %), natural gas (8 %), coal (5.5 %) and nuclear (1.5 %); emphasis for future on natural gas, hydro, ethanol and wind (Gurmendi 2009).
Colombia	Mainly dependent on hydro (81 %), gas (14 %) and coal (4 %); future government plan to encourage increase in share of coal-fired and gas-fired power generation to 20 % each (WCI, June, 2007).
Denmark	Focus on oil and natural gas and on geothermal for district heating networks (Newman 2010).
Germany	Shift away from nuclear and towards lignite and wind; elimination of subsidy on hard coal (Anderson 2010).
India	Continuance with coal and added focus on renewables like hydro, solar, wind and biomass (MGMI, July–Sept., 2011).
Italy	Presently heavy dependence on import; focus on more import of oil and natural gas (Perez 2010).
Japan	Shift away from nuclear and towards natural gas (Kuo 2009).
Netherlands	Presently, dependence mainly on oil and natural gas; priority on renewables in Government plan (Perez 2010).
Spain	For energy production, present dependence on oil (49.8 %), natural gas (20.7 %), nuclear (9.3 %), hydro (6.4 %), coal (5.5 %) and renewables (8.3 %); capacity already created to increase the share of renewables to 21 % (Gurmendi 2010).
Sweden	Presently dependence on renewables (40 % share) and nuclear; focus on increasing share of renewables (mainly wind) to 49 % i.e. 25 TWh energy by 2020 and on biomass-based hydrogen and fuel cells (Newman, Harold R, The Mineral Industry of Sweden; USGS Minerals Year Book 2010).
UK	Dependent mainly on the three traditional fuels namely coal, oil and natural gas.
United States	A mix of diverse sources of energy namely coal and nuclear mainly, also indigenous natural gas, methane and the burgeoning shale gas wells supplemented by unconventional energy sources like geothermal and wind (for energy production); oil imported from Canada, Venezuela and Middle-East (for vehicular transportation); current emphasis on continuance of the mix while at the same time reducing oil consumption by encouraging use of smaller cars consuming less fuel.

the atmosphere and for slowing the acidification of the oceans (Dyer, January 1, 2009). These ideas no doubt sound weird and bizarre now and expectedly, the environmental activists were up in arms against them. But anyway geoengineers are pursuing with such and many other ideas. A few other recent ideas and innovations with the ultimate objective of mitigating the ill-effects of the emission of CO_2

and other greenhouse gases due to coal and hydrocarbon burning, are discussed as follows.

1. *Iron fertilization*

A team of 50 Indian, German and other scientists embarked on an ambitious 70-day ocean expedition in January, 2009 to test a controversial hypothesis that had the potential to clean up as much as 1 billion tonnes of CO_2 from the atmosphere every year and to store it below the ocean for centuries. The experiment termed 'ocean iron fertilization (OIF)' involved dumping of 20 tonnes of dissolved iron sulphate in an area of 300 km^2 of ocean off Antarctica. The iron was expected to stimulate rapid proliferation of phytoplankton (microscopic algae). The phytoplankton would absorb CO_2 from air and convert it to carbohydrates; the plants would then quickly die and start sinking taking the carbon with it. The key to the success of the experiment was the depth to which they would sink. The hypothesis was that if the depth were below 1,000 m, then the carbon would remain there for many centuries; if less than 500 m, then for less than 100 years. But the OIF became a controversial proposition with the environmentalists saying that it would amount to major tinkering with marine ecosystem. The experiment has since been suspended by the German Government (Bhattacharya 2009 and MEAI, March, 2009).

2. *Bio-digestion of human waste*

The idea is to bring energy production in sync with the population increase. An innovative scheme has been working in Petropolis, a city in Brazil to recycle human sewage. It is a simple method where specially cultured organic enzymes and bacteria called 'bio-digesters' are used to break down waste water and turn it into a gas, a mixture of methane and CO_2—which is piped into homes for heating and cooking. As in July, 2009, there were 85 bio-digesting ponds in Petropolis (MEAI, Aug. 2009).

3. *Green carbon*

A US firm namely, Carbon Sciences has developed a simple technology that subjects a mixture of CO_2 and tailings from mining operations to pressure and temperature to create precipitated $CaCO_3$ (PCC) which is otherwise an energy-intensive process based on limestone. The PCC thus made has been named 'green carbon'. This green carbon technology transforms CO_2-emission to a useful product instead of simply sequestering it (TOI, Nagpur, July 14, 2008).

4. *Molecular Sponge*

Scientists of Sydney University have produced crystals with tiny molecule-sized holes which can retain gases including CO_2 (TOI, Nagpur, Sept. 14, 2010).

5. *Orange oil*

In Japan, a vulcanized tyre has been made by substituting 80 % of petroleum-based material by orange oil extracted from orange peels (*Hitavada*, July 14, 2009).

6. *Bio-char*

Charred organic materials or bio-char helped some ancient Amazon Basin inhabitants transform some of the most sterile soils into highly productive ones because they are highly rich in organic nutrients containing 70-times more carbon than surrounding soils. Now scientists have estimated that bio-char from agriculture and forestry residues can potentially store billions of tonnes of carbon in the world's soils. They see it not only as an important tool for replenishing soil but also as a powerful tool for combating greenhouse gas emission. According to a scientist named Steiner of the University of Georgia-Athens, the potential of bio-char lies in its ability to sequester and store huge amounts of carbon while also substituting fossil fuels as an energy source (Hitavada, Dec. 19, 2008).

7. *Rock storage of CO_2*

It is known that the rock peridotite has the ability to convert CO_2 into calcite; it is a slow natural process. But scientists have developed a technology that can supercharge this natural process one million times and store at least 2 billion tonnes of CO_2 every year. The technology consists in drilling into the rock and injecting heated water containing pressurized CO_2. But near-surface occurrences of peridotite are rare. There is an outcrop in Oman where the experiments were conducted (MEAI, Jan. 2009).

8. *Micro-algae*

The National Environmental Engineering Research Institute (NEERI), India has claimed to have identified four species of freshwater micro-algae from which biofuel has been produced in the laboratory. According to report, these algae could yield 40 and 200 times more fuel than jatropha and corn respectively while at the same time occupying very little space to grow. Moreover, these algae were extremely good at sequestering atmospheric CO_2 (TOI, Nagpur, Oct. 27, 2010).

9. *Nuclear waste remediation*

A team of chemists from North-Western University developed a method to remove strontium, a dangerous radioactive fission material, from nuclear liquid waste. The material developed by them was a layered metal sulphide made of potassium, manganese, tin and sulphur which preferentially attracted strontium leaving out the non-radioactive sodium which is generally present in excess amounts in nuclear wastes. Nuclear power plants generate enormous amounts of radioactive liquid waste. In the laboratory, the sulphide powder was packed in a bag and immersed into the radioactive waste. The strontium was preferentially soaked and non-radioactive potassium was given off (*Hitavada*, March 9, 2008).

10. *Nano-energy packs*

The idea is to collect solar energy in space-based power stations and transmitting the same to the Earth by microwaves. The advantages will lie in (i) more solar radiation (1.4 times) at extraterrestrial level than at the Earth's surface; and (ii) round the clock availability of solar energy independent of weather conditions (*Hitavada*, Jan. 10, 2012).

11. *Geo-polymer-based cement*

The idea for reducing CO_2-emission during Portland cement manufacturing process has been put forth by the scientists of the Research and Advanced Studies Centre, Mexico. On an average 550–650 kg of CO_2 is emitted for every tonne of cement produced (the process includes both calcination and fuel combustion) and the annual global cement production is of the order of 3.4 billion tonnes (2011 figure). In the geo-polymer-based cement, the processing temperature was brought down to 750 °C from 1,450 °C and at the same time, as claimed by the scientists of the Centre, there was no compromise with the performance of the cement (*Hitavada*, Mar. 6, 2011).

Even if a few of such innovative ideas eventually fructify to become commercial realities, it may make some contribution to the energy security of the world.

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Chapter 7
Groundwater and Water Management

The advent of water on the Earth's crust is not well understood. In 2009, some scientists of UK have suggested that meteors, which bombarded the Earth approximately 4 billion years ago, delivered 10 billion tonnes each of CO_2 and water vapour to the Earth's atmosphere and the Earth held them in its atmosphere by virtue of its magnetic field. Then when the temperature decreased to less than 100 °C, part of the hot vapours became water and dropped on to the surface. At present the total volume of water (including the icecaps and glaciers) below the surface of the earth, on its surface and over it (in the form of vapour) adds up to 1.35×10^{18} kl and the scientists doubt that the origin of so much water might not be so simple. According to them other factors such as volcanic eruptions bringing forth the hydrates from within; water-containing comets, asteroids and meteorites, primordial organisms and plants could have contributed to the formation of water (Chatterjee 2013).

Water as such is not a mineral by the conventional definition; but the mode of occurrence and the method of recovery of groundwater bear some similarities with petroleum and other mineral resources. Other similarities include invisibility and fixed location of reservoirs and also the techniques of exploration deployed. For these reasons, groundwater is recognized as a mineral by the laws of some countries including India. The Supreme Court of India in a judgment in 1996 has held: 'Mineral means all substances which can be obtained from the earth by mining, digging, drilling, dredging, hydraulic operations, quarrying or by any other operation'.

However, water is a peculiar commodity from the geologists' and the mineral economists' points of view. Its fourfold man-made division into atmospheric water, surface water, hyporheic water and groundwater defies any economic logic. Although scientists treat them differently—meteorology for atmospheric water and rain/snowfall, hydrology for surface water and hydrogeology for groundwater; each behaves as a part of the whole water resource system. Throughout history, man has been fulfilling all his needs of water—for drinking, for bathing, for washing, for farming and for industries—directly through the surface freshwater, groundwater, rainwater and snow; and the animals and other lesser forms of life draw benefits and

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sustenance from all the four forms of water. Moreover, there are constant and smooth interactions amongst all the forms of water. In fact availability of water as such played a critical role in the beginning of human settlements and civilization which invariably centred on rivers and water wells. Hence it is difficult from the economic viewpoint to treat groundwater in isolation with other forms of water.

7.1 Quality of Water

Usability of any form of water depends on its quality and purpose of use. The parameters of quality are as follows.

1. Acidity/Alkalinity

The degree of acidity/alkalinity is measured by what is called ‘potential of hydrogen (or pH) value’ on a scale ranging from 0 to 14 with 7 representing neutrality and higher the value the stronger is the alkalinity. Both very strongly acidic and very strongly alkaline water would corrode the plumbing components in the water transportation system if the water is to be transported through pipe lines.

2. Hardness/Softness

Hardness of water is caused by the presence of the insoluble carbonates and sulphates of calcium and magnesium, which tend to precipitate in the form of scales when the water is boiled. Roughly, it can be measured in terms of the content of these salts as:

Soft	0–20 mg/l
Moderately soft	20–40 mg/l
Slightly hard	40–60 mg/l
Moderately hard	60–80 mg/l
Hard	80–120 mg/l
Very hard	>120 mg/l

Hard water can be softened by treating it with a softener like zeolite or ion-exchange resins. Hard water per se does not affect the human health, but, if the water is delivered through pipelines additional metallic impurities like cadmium, copper, lead and zinc may enter the water from the pipes.

3. Microbial Contaminants

The most common microbes in water are the heterotrophs. These bacteria get their nourishment from the carbon and nitrogen of organic compounds and form colonies where such nutrients are aplenty.

4. Chemical Contaminants

Some of these are considered desirable and some others harmful. The desirable ones are the disinfectants which kill the bacteria of water and include chloramines, chlorine and ClO_2, which may be present in water naturally or, otherwise, may have to be added. The harmful chemicals are the organic carbons and some inorganic elements and compounds like arsenic, fluoride, lead, mercury etc.

These parameters of quality are critical for water whether used for human, animal or industrial consumption. In case of groundwater, pollution takes place when metals and minerals from underground rocks and deposits migrate into it in excess amounts and at the same time the rate of withdrawal is excessive. Their higher concentration may also be due to human activities like mining, use of chemical fertilizers and pesticides, excessive use of phosphorus- and sulphur-containing detergents, poor drainage system etc.

7.2 Economic Significance of Water

The total volume of water in the hydrosphere of the Earth has been estimated to be 1.35×10^{18} kl. This resource is constant with no addition or depletion. Of this total resource, 97.21 % is saline water in oceans and lakes; and the balance 2.85 % is freshwater locked up in the icecaps and glaciers, residing in the atmosphere, soil, lakes, streams and groundwater aquifers. From the economic point of view, water can be classified as follows.

(a) Virtual water: It is the volume of water embedded in a product and not consumed or polluted during the process of production. Examples are beverages, juicy fruits etc.
(b) Blue water: It refers to the rain water which is soaked into soil and is used by agricultural crops.
(c) Green water: It refers to the water used in irrigation.
(d) Grey water: It is the amount of water which is required to dilute pollutants in water in order to bring their concentration down to accepted levels.

The economic significance of the different entities of water is discussed as follows.

7.2.1 Groundwater and Surface Freshwater

It is impossible to separate these two from the economic standpoint. Both can be used interchangeably depending on the accessibility and cost of collection. But the dependence on groundwater is, now-a-days, increasing continuously at an alarming rate because of progressive deterioration of quality of surface freshwater mainly due to man-induced pollution triggered by increasing discharge of wastes associated with increasing industrialization.

The groundwater resource in the world has been estimated to be about 8.33 quadrillion kilolitres, out of which about 4.17 quadrillion kilolitres occur within the supposedly economically exploitable depth of 800 m. But in addition to depth, the factors like nature of rock and pollution make a part of this resource unexploitable or unusable. But this resource keeps changing due to continuous depletion and recharging. And same is the case with surface water resource which is difficult, if not impossible, to estimate because of its naturally dynamic nature and also human interference in the form of dams, barrages and weirs. Besides, the resources of both the groundwater and the surface freshwater at a particular point of time depend on rain and snowfall, evaporation and percolation into underground aquifers. However, an attempt was made in India to make some estimation of the resource of the groundwater and the surface freshwater in 1994. According to those estimations, the total groundwater resource in that year was 600 billion kilolitres out of which usable portion was less than 260 billion kilolitres; and the surface freshwater resource was 1,780 billion kilolitres out of which 310 billion kilolitres or only 17 % was utilizable.

The uses of groundwater and surface freshwater are interchangeable and depend solely on the availability, cost and quality. The broad categories of the large scale utilities of freshwater are as follows.

(a) Agriculture

According to a United Nations study of 1999, worldwide the agricultural activity consumed 69 % of the total anthropogenic water withdrawals. In many countries, groundwater accounted for a substantial portion of this water consumption. According to a separate estimation, 48–50 % of cultivated land is irrigated from groundwater. Certain agricultural activity consumes huge volumes of water—about 500 m^3/tonne in case of cassava to almost 23,000 m^3/tonne in case of coffee. It is true that part of the water consumed by the plants goes down to recharge the groundwater and the consumption is also coming down due to improved farming technology like drip irrigation; but at the same time, the use of more and more chemical fertilizers and insecticides are causing deterioration of the quality of the groundwater. The annual consumption of water for different crops is shown in Table 7.1 which reveals that agriculture is mostly dependent on irrigation (green water).

(b) Drinking

Drinking or potable water is sourced to both surface freshwater and groundwater and is defined in a generalized way as the water that is not having impurities in amounts sufficient to cause disease, is safe for humans, animals and birds to drink and is not containing salts in excessive quantities so as to be called mineral water. Obviously, this definition will vary with locality and will depend on the intrinsic immunity of the people of a locality and the species. What is safe to drink for a villager in India may not be safe for a European; and what is safe for an animal or a bird may not be so for a human. Accordingly, the permissible limits of pollutants also vary.

(c) Industry

Of the total anthropogenic water withdrawal, 24 % goes for industrial consumption. All industries consume water directly or indirectly. An idea about the magnitude of requirement of water in different industries can be had from the following data pertaining to some typical units.

Table 7.1 Crop-wise annual water consumption (Average of 5 years during 2000–2004)

Crop	Average annual water consumption during 2000–2004						
	Green		Blue		Grey		Total
	Quantity (m^3/t)	Share in the total (%)	Quantity (m^3/t)	Share in the total (%)	Quantity (m^3/t)	Share in the total (%)	Quantity (m^3/t)
Rice	2,527	73	735	21	212	6	3,474
Maize	2,395	96	75	3	13	1	2,483
Cassava	487	95	8	1	19	4	514
Soybean	1,644	84	314	16	0	0	1,958
Groundnut	2,962	95	162	5	0	0	3,124
Coconut	2,881	99	0	0	16	1	2,897
Oil palm	802	94	0	0	51	6	853
Banana	875	100	0	0	0	0	875
Coffee	21,904	96	0	0	1,003	4	22,907
Cocoa	8,895	94	0	0	519	6	9,414

Source: Wikipedia, 2006

- Brick industry: 0.5 l/brick/day
- Tanning industry: 25 l/kg of raw hide/day
- Handmade paper: 54 l/kg/day
- Dyeing, 80 l/kg cloth/day
- Dairy farming: 150 l/cow/day
- Crude steel in India: 3 m^3/tonne
- Beverage (soft drink): 6.2 l/l of beverage
- Coal-based thermal power in India: up to 0.15 m^3/unit electricity

The outputs from such industries are in hundreds of millions of tonnes of products each year worldwide and the requirement of water turns out to be enormous. For such industries, groundwater is normally not feasible and river/reservoir water is the only option. In fact, now-a-days, in any large new industrial venture in India water has become the third critical input after land and mineral/metal. And many rivers in India being extremely sensitive to the unpredictability of monsoon rainfall, the water availability for the industries becomes very often tight. In order to optimize the consumption of water, recycling of the used water after treatment has become an established practice in many modern industries.

Hard water is highly harmful for industries, because it will tend to deposit scales of lime and magnesia on boiler pipes and machinery parts. Since large quantities of water are used continuously, the scale deposition will also become very large resulting in breakdowns and loss of productivity.

(d) Mineral Water

Mineral water is of two kinds—natural and fortified. Both contain at least 25 ppm dissolved salts like calcium, iron, magnesium, sodium, boron, fluorine and Epsom salt. The former is obtained from natural springs while the latter is made by first distilling/desalinating ordinary water and then adding certain nutrients.

(e) Household Activities

Of the total anthropogenic water withdrawal, 24 % is consumed by households and other municipal users for activities like laundry, bathing, hygiene etc. Potable water is not necessarily required for these purposes, but the water should not be hard, because hard water does not yield enough lather easily and considerably more quantities of it will have to be consumed. Moreover, if machines are used for washing then hard water will tend to deposit scales of lime and magnesia on the parts and damage them.

Between groundwater and surface freshwater, the former is preferable from economic point of view due to the following reasons.

(a) Groundwater is rechargeable. Though surface freshwater also gets recharged by rain and melting glaciers, much of it tends to flow out through rivers and streams and it requires human intervention to hold it in reservoirs.
(b) Many rivers flow across international borders and, within a country, across interstate boundaries. Consequently, such river water has become a source of mistrust amongst nations and states. Over 260 water basins of world transcending across national borders are covered by more than 3,800 unilateral, bilateral and multilateral conventions and treaties (e.g., Indus Water Treaty between India and Pakistan). In contrast, groundwater, being invisible, has still not created this kind of problem.
(c) Groundwater has the advantages of location and accessibility. Surface water sources and flows are confined by ground topography to specific locations and channels not accessible to one and all.
(d) Unlike surface water, groundwater is not vulnerable to wide scale man-induced external pollution because some degree of filtration of the percolating surface water takes place while passing through the rock strata.

Groundwater is mainly used for drinking and irrigation purposes in India although in areas far away from a source of surface freshwater, certain industries also depend on groundwater.

7.2.2 Atmospheric Water

Atmospheric moisture is an essential link in the Earth's hydrologic cycle (i.e. water cycle). But it becomes economically useful only when it comes down in the form of rain or snow. Part of this rain water or the water from the melting snow percolates down and recharges the groundwater aquifer and the balance flows away through the drain pipes or as surface run-offs. In developing countries vast tracts of non-irrigated agricultural land depends solely on rain water and snow-water for cultivation. But this source of water is highly dependent on the vagaries of climate. In many places in India, rainwater harvesting is becoming a practice and even legally enforced. It consists of a system to channelize the rainwater precipitating on rooftops and courtyards into collectors (tanks and wells) for use during times of water-scarcity. But this has to be done in every house, office and factory—a huge task to organize.

7.2.3 Wetland Water

Wetlands are natural depressions (e.g., river basins) where the soil is saturated with moisture and groundwater table is near or above the surface. These are characterized by shallow pools of water including marshes, bogs and swamps. These are environmentally very significant (discussed later in this chapter). As regards the more direct economic benefits to humans, the wetlands act as natural sponges to absorb and reduce the impact of flood and they also serve as filters to hold the soil nutrients and sediments, preventing them from flowing into rivers and lakes (these soil nutrients are vital for agriculture). Furthermore, the organisms harboured by wetlands decompose the sewage and effluents before they reach the rivers and lakes, thus helping the river and lake waters to remain free from impurities. These economic values are generally not appreciated by common people who often treat such lands as mere wastelands.

7.2.4 Seawater (Including Brackish Water)

Sea water is used for drinking, agriculture and industrial activities after desalination. Well established technologies (multi-stage distillation and reverse osmosis) are in place to desalinate sea water. Some countries like Bahrain, Kuwait etc. have zero to near-zero natural freshwater supply. They are making up through desalination of seawater. Desalination plants are operating in many countries of the world where supply of freshwater is deficient. For example, per capita availability and consumption of freshwater in Kuwait, Israel and Jordan is nil, 124 m^3 and 138 m^3 respectively (cf. Canada 92,000 m^3).

Besides, desalinated sea water is used in industries located in coastal areas, military bases located in remote islands and aboard sea-going vessels. In India, Kudankulam Nuclear Power Plant is sourcing its water to the sea. An advantage of such plants is that salts are obtained as byproducts for human and animal consumption. Even without desalination, sea water is used for certain purposes like cooling of industrial plants and machinery.

7.3 Role in Environment

7.3.1 Hydrologic Cycle

Water as a whole (and not the different man-made classification entities individually) plays a key role in maintenance of life and ecosystems on the Earth. Each entity (atmospheric water, surface freshwater, groundwater and sea water) is by itself an essential link in the Earth's hydrologic cycle. In this cycle water moves from one entity to another in a closed circuit; and during such movement its state

Table 7.2 Average residence times in different reservoirs within the hydrologic cycle

Reservoir	Average residence time
Antarctica	20,000 years
Oceans	3,200 years
Glaciers	20–100 years
Seasonal snow cover	2–6 months
Soil moisture	1–2 months
Groundwater (shallow)	100–200 years
Groundwater (deep)	10,000 years
Lakes	50–100 years
Rivers	2–6 months
Atmosphere	9 days

Source: Wikipedia, Jan. 12, 2013

changes from liquid to gaseous to solid and back to liquid and so on. Thus water of the sea moves to atmosphere and then precipitates on to the Earth as freshwater and snow, part evaporates back to atmosphere, part percolates to groundwater aquifers, part remains in lakes and rivers and the balance runs off to sea again; part of the groundwater also comes back to the surface as springs. The water cycle involves exchange of heat at every stage leading to temperature changes, wind currents, ocean currents and thus it influences the climate. It also involves reshaping of the Earth's topography through the processes of erosion and sedimentation, growth of forests and formation of deserts. Wherever in whichever form the water resides within a hydrologic cycle, it is called a 'reservoir' and 'residence time' of a reservoir is the average time a water molecule will spend in that reservoir. It is a measure of the average age of the water in that reservoir. Average reservoir residence times in each of the reservoirs are variable as shown in Table 7.2.

Needless to say that human interference may alter the above residence times.

7.3.2 Watershed

Watersheds are basin-like land forms defined by high ridges that descend into lower elevations and stream valleys. A watershed carries water 'shed' from the land after rainfalls and snowmelts. Drop by drop, the water is channelled into the soils, groundwater, creeks and streams and then finally into larger rivers and sea. The water flowing over and beneath the Earth's surface is affected by all it comes in contact with—land and soil, through which it traverses. Thus all anthropogenic activities on the land affect water quality for all those living downstream.

While the hydrologic cycle is itself a biogeochemical cycle, watershed is a key factor in the cycling of various biogeochemical elements and substances. Run-off is responsible for almost all of the transport of eroded sediments and phosphorus from land to water bodies; the salinity of sea water is derived from erosion and transport of dissolved salts from the land; eutrophication of lakes is primarily due to phosphorus applied in excess to agricultural fields in the form of fertilizers and then transported overland and down rivers; and both surface run-off and groundwater flow play significant roles in transporting nitrogen from land to water bodies.

7.3.3 Wetland Water

A wetland represents a transition zone called 'hydrorheic zone' in which close interactions between groundwater and surface water take place and these are biologically very diverse and such lands significantly support the ecosystem. In this zone mixing of the two waters takes place and the metals, micro-organisms etc. keep migrating from the groundwater to the surface water influencing the quality of the surface water. Some aquatic species need the light, dissolved oxygen and temperature fluctuations of the surface water as well as the darkness, less oxygen, dissolved organic carbon, various nutrients and stable temperature of the groundwater environment, and they thrive in the wetlands. Some microbes living in the wetlands go into the grasses and plant leaves providing food for grazing animals which in turn provide food for carnivorous predators. Thus equilibrium of the ecosystem is maintained.

Besides, the wetlands serve as sites for summer sojourn of many migratory birds feeding on the rich and unique biodiversity. Wetlands also render thermal service to animals living in the semiarid regions. In such regions, the cooler groundwater comes up to the hotter surface through the hydrorheic zone thus moderating the effect of heat on those animals.

7.4 Policy and Management

7.4.1 Broad Issues Involved

A national policy reflects the will of the people of a country and takes care of the needs of not only the present generation but also those to come. In other words it is a long term goal towards which certain kind of activities should be directed. Obviously, formulation of such a policy in respect of water needs to factor a host of issues. These issues can be broadly grouped into the following categories.

7.4.1.1 History of Use of Water

History of use of surface freshwater is as old as life itself. In fact the first living organism was born in water at least 3.7 billion years ago. The great civilizations which made profound impact on the history of mankind were all river-centric—Hwang Ho river in China (7000 BC); the Nile Valley Civilization in Ethiopia-Egypt region (6000–300 BC); the Assyrian Civilization around Euphrates-Tigris river basins of the central region of Mesopotamia covering present day Iraq, Turkey, parts of Israel and Iran; the Dravidian Civilization (5500–1900 BC) followed by the Indo-Aryan Civilization on the banks of the river Indus. But the earliest evidence of exploitation of groundwater unraveled so far dates back to sometime during 10,500–8000 years ago when a batch of early Neolithic men intending to settle down in Cyprus dug a 5-m deep cylindrical water-well. In India, the practice of accessing groundwater through stepped wells was in vogue during the times of the Indus Valley Civilization in the 3rd millennium BC or earlier. But all along, people everywhere have been looking upon water—whether surface freshwater or groundwater—as a freebie provided by nature and even digging of wells did not require any specialized skill. The burden of such a long history is indeed too heavy to shed.

7.4.1.2 Resource Nationalism

Resource nationalism comes into play when there is scarcity and consequent insecurity. During the drought year of 2009, there were reports of people of a village in Bihar (India) guarding with guns in hand throughout the day and the night their pond—the only one in the entire area filled up with water during summer months—against those of a neighbouring village. Quarrels amongst village women over water are common in India. At a state level, rivers flowing across interstate boundaries are sources of perennial feud between people of the states; and if there is a dam in the upstream state, it is not uncommon to find the people living there blocking the flow of river to the downstream state. In India such disputes often end up in litigations and judicial interventions. If the issue is further scaled up to the international level, then the problem is more acute. It has now become practically impossible for an upstream country to construct a dam on an international river without entering into a treaty with the downstream countries.

However, the problem has not reached such a serious state in case of groundwater primarily because of invisible nature of the resource, although wars have been fought over oil—another underground liquid resource. The reason is that oilfield development involves large companies with huge capital and highly skilled manpower in contrast to groundwater which is generally exploited through wells dug or drilled by innumerable private citizens in their private premises and fields with the help of unskilled or semiskilled workers oblivious of its behavior and flow underground.

7.4.1.3 Quality of Water

Rivers and closed water bodies like ponds, lakes are getting increasingly polluted due to disposal of urban sewage and industrial effluents. According to a UN estimation of 1985, as much as 70 % of the global surface water had already become unfit for human consumption. According to a report by the Central Pollution Control Board (CPCB), India the industry-wise discharge of wastewater is as shown in Table 7.3.

Table 7.3 Industry-wise wastewater discharge in India

Industry	Annual consumption of freshwater (million m^3)	Annual wastewater discharge (million m^3)	Wastage (%)
Thermal power	35,157	27,000	77
Engineering	2,020	1,551	77
Pulp and paper	906	696	77
Textiles	830	637	77
Steel	517	397	77
Sugar	195	150	77
Fertilizer	74	56	76
Others	314	241	77
Total	40,013	30,728	77

Source: CPCB, India

The wastage of polluted water by the industries in India is indeed alarmingly high. But one reassuring fact is that the industries together consume only 6 % of the total freshwater drawn.

According to estimates by the US Department of State (2011), one and a half million children in the world still die each year from diarrheal diseases related, inter alia, to poor quality drinking water; and degrading water quality will further increase disease, undermine economic growth, limit food production and become an increasing threat to peace and security.

As regards groundwater, the causes of pollution are depletion of its resource due to over-pumping and natural pollution at some places due to certain deep-seated mineral bodies. For example, the arsenic-rich and fluorine-rich mineral occurrences deep underground in some places have caused increase in arsenic and fluorine concentrations. Arsenic pollution is also caused by certain man-made reasons like excessive use of phosphorus- and sulphur-rich soaps and detergents and accumulation of the wash water due to poor drainage. Pollution may also take place due to percolation of industrial and mine effluents. Sometimes metals like arsenic, cobalt, cadmium, lead, zinc—all poisonous above a certain limit—contained in rocks and certain chemicals used for processing of minerals may be in continuous contact with water. Eventually they may get washed away and carried into surface water and also into groundwater by seepage. Even atmospheric water is not free from pollution as exemplified by acid rain prevalent in some Scandinavian countries.

7.4.1.4 Distribution Amongst End-Users

Domestic (drinking by humans and livestock and household works), agriculture and industry are the main contenders for drawing freshwater. According to UN estimates, the status of water consumption in the three main sectors in the world is as given in Table 7.4.

Table 7.4 Broad sector-wise water consumption (world)

Sector	Freshwater consumption (% of total)		
	World	High-income countries	Low and middle-income countries
Domestic	9	11	8
Industrial	22	59	10
Agricultural	69	30	82

Source: Chatterjee (2013)

Table 7.4 brings out an emerging scenario which is disturbing. All low- and middle-income countries are endeavouring to join the high-income group. When they succeed, agricultural consumption of water may come down, but there will be an enormous increase in the consumption by the industries. This may bring in the problem of pollution and wastage in huge proportions.

Among the industries in India, thermal power alone consumes about 88 % of the total freshwater drawn by all the industries together. However, in India the anti-industry campaign by the environmental activists is forcing the Government to relegate industries to a much lower priority after agriculture. In the year 2000, as much as 89 % of the freshwater drawn was used by the farmers and only 6 and 5 % by industries and domestic sector respectively (*Hitavada*, Nov 29, 2012).

7.4.1.5 Science, Technology and Innovation

Water has become too important to be left to traditional approaches and it is now imperative that technology is invoked in its management. While there is no simple technological fix for global water challenges, current approach recognizes the potentially game-changing role of innovation. It is easier to quantify the volume of potable water in rivers and lakes but it is much harder to gather information about below-ground aquifers, which cannot be mapped using traditional land surveys and cartographic tools. U.S. technical agencies have developed new remote sensing platforms that allow detection of changes in groundwater levels from space. When combined with ground-level measurements, they allow a better understanding of certain aquifers. This has especially important implications for drought-prone regions throughout the world, where changing rainfall patterns are devastating agricultural livelihoods. To predict floods and famine, the U.S. employs other satellites and ancillary measurements, and shares this information with vulnerable nations through a free and open exchange of data. The US Government also encourages the deployment of existing low-tech solutions such as sand filters, solar disinfection, and household water purification that can be built from local materials and scaled up through market-based mechanisms (US Department of State, March 4, 2011).

In India, an innovative experiment has been carried out in the water-scarce area of Dhule district in Maharashtra to improve the recharging of groundwater. Streams were deepened and weirs without doors constructed; the storage capacity of the weirs was determined by multiplying the water required by the local villagers for drinking and agriculture by three thereby creating enough hydrological pressure on the soil for water to percolate down (TOI, Nagpur, Jan 11, 2013).

The innovations are limited to conserving water and increasing its availability; for purification of contaminated water also, research and innovation are intensifying. Some species of earthworm have been identified in the Department of Ecology & Environmental Science, Puducherry University, India which can take in heavy metals like cadmium, chromium, lead and nickel ten times their body weight, break them down with the help of their enzymes and convert them to body tissue (TOI, Nagpur, Oct 4, 2012). In another innovation, the scientists of University College, London have cultured a new type of bacteria which can consume arsenic compounds from contaminated water (*Hitavada*, Sept 11, 2008).

7.4.1.6 Socio-politics

People of different countries have different attitudes towards water. Universally, they develop sentimental attachment to certain rivers and lakes which have provided them with livelihood through generations, which have inspired art and culture and have been centres on which mythologies were built up; they were even associated with evolution of some religions. In short, those rivers have influenced the socio-cultural history of many nations. In India, there are rivers like Ganga, Yamuna, Brahmaputra, Godavari, Cauvery and Periyar which have been deified and are worshipped with devotion by common mass; many temples have been built on their banks and they have given birth to and nurtured many superstitious customs. Obviously, people belonging to a country or a religion are highly sensitive about honour and purity of such rivers flowing in their countries. No politician can afford to overlook such sensitivities of his people.

7.4.1.7 Economics

Economics is about not only demand–supply-cost of water but also opportunity costs in relation to other necessities. Water is no longer just a temporary concern for the summer months; now there is a global concern over its declining quantity and quality. Total resource of water in the entire hydro-system is finite and its demand by the burgeoning population, ever-expanding industrial sector and agriculture is increasing. So far, the relatively less costly surface freshwater and groundwater have been regarded as renewable and their replenishment through migration of water from other entities within the hydrologic cycle has been taken for granted. But this complacence is fast giving way to a hard realization of shortage of supply and cost in terms of both price and the sacrifices that will have to be made.

The economic value realization of the water consumed by the industries of different countries was estimated by the World Bank in 2001 as shown in Table 7.5.

From Table 7.5, it is clear that the economic value realization of industrial water in India is the lowest implying poor efficiency of water conservation by the Indian

Table 7.5 Country-wise economic value realization of industrial water use in 2000

Country	Industrial water use in 2000 (billion m^3)	Industrial production in 2000 (million US $)	Economic value realization of industrial water in 2000 ($/$m^3$)
Argentina	2.6	77,171	30.0
Brazil	9.9	231,442	23.4
India	15	113,041	7.5
Korea, Republic of	2.6	249,268	95.6
Norway	1.4	47,599	35.0
Sweden	0.8	74,703	92.2
Thailand	1.3	64,800	48.9
UK	0.7	330,097	443.7

Source: World Bank (2001)

industries. In the recent times, under compulsions of increased availability constraints, the Indian industries have adopted some modern technologies to reduce water-intensiveness and to treat and recycle used water.

Since the hydrologic cycle is now highly distorted due to industrialization and global warming which may not be possible to be reversed in the foreseeable future, the option gets limited to low-water economy (cf. low-carbon economy). This means reducing the demand for water in agriculture through low-water technologies (e.g. drip irrigation), its recycling in the industries, changing people's food habits in favour of low-water crops and its conservation by the people at large. In other words the 'water footprint' (see Glossary) will have to be maintained at the minimum. All these will need to change the attitude of the people. At the end, the goal should be to ensure match between the rates of withdrawal and recharge (Nilekani et al. 2011).

7.4.1.8 Sustainability

Water is fast becoming one of the world's not just development challenges but also security threats. Many conflicts are caused or inflamed by water scarcity. In the countries from Chad to Afghanistan and Pakistan which lie in an arc of arid lands, water scarcity is leading to failed crops, dying livestock, extreme poverty and desperation. Studies by UN and World Bank tell about water supplies being under stress in large parts of the world. These studies attribute the reasons to burgeoning populations, depletion of groundwater, wastage, pollution and effects of man-made climate change. The consequences are harrowing: drought and famine at increasing frequency, loss of livelihood, spread of water-borne diseases, forced migration and even open conflict. The United Nations Human Development Report for 2006 has said that by 2025, if current global water consumption continues, more than three billion of the world's 7.9 billion people in that year will be living in areas where water is scarce. And the United Nations Population Fund, in 2003, has predicted that the world will begin to run out of water in 2050. According to a report of the National Aeronautics and Space Agency (NASA) of US, the groundwater level in northern India had been declining at the rate of 30 cm/year during the decade 1999–2008 due almost entirely to human activity; between 2002 and 2008, more than 65 km^3 of groundwater had disappeared from the aquifers in the state of Punjab and the area surrounding Delhi. Sustainability of water resource is about meeting these challenges.

Sustainability of water supply is not a quick-fix approach nor is a local or even country-specific issue. It is a complex and multidimensional approach involving steps at global as well as national levels as under.

(a) Diplomatic efforts for arousing global awareness and cooperation
(b) Building capacity through new partnerships
(c) Leveraging new financial resources
(d) Developing human skill and flexibility to work with local communities
(e) Synergizing technology, creativity, politics and business

In order to be effective, a policy must address all these issues (US Department of State 2011; Pandit et al. 2009).

7.4.2 Policies

Many governments have become aware of the urgency to formulate water policies with a view to setting the runaway slide towards self-destruction on check before it is too late. During the twentieth century, all attention was on oil and energy security. In twenty-first century attention has been turned towards water in some countries which have recognized the water challenges. Piecemeal laws that are in place in those countries have become outdated and ineffectual and an increasing number of aquatic ecosystems are in danger of collapse. The problems faced by many countries can be summed up as follows.

1. Lack of institutional mechanism to collect data
2. Growing demand due to increasing population and industrialization
3. Deteriorating water quality
4. Conflict amongst local, state and central levels
5. Confusion over authority due to diverse agencies responsible for different aspects of water management and regulation
6. Old mindset that do not account for the realities of the twenty-first century and for recent advances in scientific and technical understanding of both water problems and solutions
7. Lack of vision
8. Differing characteristics of water resources
9. Variation of political frameworks and governing mechanisms not only across countries but also, in some cases, within the countries
10. Competition amongst water-users
11. Pricing issues

Very few countries in the world are fully engaged in recent years in efforts to revamp outdated institutions, laws, technologies, and strategies for managing freshwater and put in place new and innovative approaches to sustainable water management. Internationally, many countries share a commitment to ‘soft path’ approach which includes

(a) Strategy for more sustainable water management
(b) Recognition of limits to traditional approaches
(c) Recognition of the importance of critical ecological services such as nutrient cycling, flood protection, aquatic habitat, waste dilution and removal, aesthetic values
(d) Satisfaction of human needs such as clean potable water, hydropower, agriculture, commercial fishing, and recreation
(e) Less reliance on traditional hard infrastructure that transports water over long distances or centralized water supply and wastewater treatment
(f) Encouragement to more local water supply options
(g) Greater conservation and efficiency at homes and offices
(h) Precision irrigation technologies in farms
(i) Recycling and re-use of water
(j) Managing local surface and groundwater resources together
(k) Smarter use of economics such as water pricing and innovative markets
(l) Developing better urban and agricultural practices to retain water (e.g. rainwater harvesting and conservation-oriented tillage)

The international reform efforts are based on public involvement and acceptance by local communities and also making the institutions more adaptable and flexible so as to be able to respond to increased uncertainties in the future such as climate change (Smith et al. 2012).

The status in some of the countries are discussed as follows.

7.4.2.1 India

Apart from enactment of the Water (Prevention & Control of Pollution) Act in 1974, no government initiative was taken for the next three decades. This Act was common for both surface and groundwater, but by and large, the two resources of water have all through been treated as separate resources requiring separate strategies for management. Vast tracts of agricultural land are not irrigated and agriculture is largely dependent on groundwater irrigation except in areas around reservoirs. But construction of dams is inadequate due to problems of land acquisition, displacement of local population, submergence of forests and paucity of capital. The problems with regard to exploitation of groundwater for farming are threefold as under:

(a) The Groundwater Act, 2005 requires all farmers to obtain permit from the Groundwater Authority before they can apply for electricity connection.
(b) High electricity tariff discourages use of electric pumps.

(c) High energy cost for pumping due to dependence on costly diesel.

In spite of these disincentives, many areas of India face problems of over-exploitation and continuous lowering of groundwater table. Almost a third of groundwater aquifers are semi-critical or critical. Some scientists have predicted that at current rate of extraction, 60 % of the groundwater blocks may turn critical by 2025 (TOI, Nagpur, July 18, 2012). The reasons are as under.

(a) Since 1967 credit facilities through institutional finance for groundwater development have become freely available (Kamath 1987).
(b) There has been an increasing trend to supply electricity to farmers practically free or at highly subsidized rates in many states due mainly to political reasons.
(c) Informal groundwater markets enable small and medium farmers who otherwise may not want to invest in a well or tube well (Mukherji 2012).
(d) Unregulated competition for deepening of bore wells in adjacent farms with a view to drawing more water by one than the other (Jhunjhunwala 2012).
(e) Rampant use of hand pumps in rural homes and also in urban homes due to inefficient and unreliable water supply.

As per Indian Constitution, water is a state subject and the Union Government cannot make laws in this respect. The Union Government, under Article 252 of the Constitution, can at best formulate a broad policy which may serve as kind of models for state governments to make their own laws. Till 2012, there was no regulation for extraction of groundwater and its coordination among competing uses. On December 28, 2012, while recognizing that the institutional and legal structures were inadequate and fragmented and in urgent need of reform, the Government of India announced a 'National Legal Framework of General Principles on Water' (commonly referred to as draft water policy). Its strength lies in the fact that it treats water holistically in contrast to the general tendency of treating surface freshwater and groundwater separately. The broad features of this framework are as under.

(a) The framework will be an umbrella statement of general principles governing the exercise of legislative, executive and the devolved powers of the centre, states and local governments.
(b) Groundwater will be treated as a common community resource and not as a private right as currently exists in order that basic needs of drinking water along with livelihood of poor farmers are protected.
(c) A tariff mechanism for all kinds of water uses in the country will be created.

However the draft policy is silent on maximization of efficiency of utilization of water, equitable distribution, market-driven and non-market incentives to establish water recharging structures (TOI, Nagpur, July 18, 2012; *Hitavada*, Dec 28 & 29, 2012).

Meanwhile, on December 17, 2012 the Government of the state of Maharashtra announced a new water resources allocation policy the scope of which is limited only to surface freshwater (TOI, Nagpur, Dec 18, 2012). The stipulations of this policy are:

(a) Ideally, only 20 % of water should be for non-irrigation purpose; this may be further reduced at times of drought.
(b) Of the water for non-irrigation purpose, drinking will be given higher priority.
(c) Water-use efficiency has been accorded importance.
(d) Emphasis has been given on treatment of effluents and quality improvement.
(e) Recycling by non-irrigation users will be made compulsory with provision of penalty in case of non-compliance.
(f) Non-irrigation users will be encouraged to take water from other sources like groundwater.
(g) Maximum per capita consumption has been fixed for local bodies which will vary depending on population.

Many river-flows in India are committed to serve purposes of agriculture, drinking and only the balance is available for industries. But the practice has been ad hoc.

7.4.2.2 United States

In the 1970s, the National Water Management Act was enacted which set the road map for water management as under:

(a) Creation of National Water Commission
(b) Review of present and anticipated water resource problems
(c) Projections of water requirements
(d) Conservation and more efficient use of existing supplies
(e) Reduction in pollution
(f) Innovations to encourage the highest economic use of water
(g) Inter-basin transfers
(h) Technological advances

Subsequent to this Act, Clean Water Act was enacted and significant improvements in wastewater treatment have been achieved. Besides, there has been an overall reduction in per capita water use associated with conservation and efficiency as well as some changes in the economic structure of the country.

At local level some good initiatives have been taken and enforced by the authorities for maintaining water availability from the Tennessee reservoir. The Tennessee Valley Authority faced a problem of too much silt flowing into the reservoir; the Government made it compulsory for the farmers to make bunds of a particular height along their fields; as a result silt got trapped in the fields and silt flowing into the reservoir was reduced (Jhunjhunwala 2012).

But still, the old fragmented approach to water continues. More than 30 federal agencies, boards and commissions have water-related programmes and responsibilities. The complex legal and institutional framework of water management has evolved through 200 years and has never undergone comprehensive review or integration (Smith et al. 2012).

7.4.2.3 European Union

The European Union Water Framework Directive was passed in 2000. It integrated into a single legislation the water policies of the member states. It is based on three main issues which are as follows.

(a) *Ecology:* No human-induced disturbance to the physical (by implication should include nuclear), chemical, hydro-morphological, and biological elements
(b) *Governance:* Decentralization of governance to water management authorities at the river basin district level and involvement of locals in decision making
(c) *Economy:* Determination of true cost of water and full-cost recovery by water suppliers after factoring the estimates of the social, environmental, and economic effects of recovery and also the long-term forecasts of supply and demand for water
(d) *Review of plans and production:* Active involvement of all interested parties
(e) *Coordination:* Creation of a ‘competent water authority’ to ensure coordination among all stakeholders and bodies concerned with water management

Till 2009 the issue of the economic analysis was not put in practice. As regards governance, in view of the different sociopolitical environments prevalent in the member states and the institutional infrastructure already in place, the issue has been kept flexible; and the member countries will be free to designate their own national bodies as ‘competent authority’ such as Environment Agency in England, National Institute of Water in Portugal and the River Basin Water Agencies in France (Smith et al. 2012).

7.4.2.4 Russia

In the Russian Federation Water Code, 2006, focus is on integrated regional water management. The features are

(a) Surface and groundwater treated as one integrated resource
(b) Prioritization of protection of water bodies (both surface and ground) over their use
(c) Environment preservation
(d) Priority to drinking over other domestic purposes
(e) River basin approach
(f) Introduction of integrated water basin management schemes
(g) Improved involvement of civil society in decision making
(h) New water-quality standards for a range of chemicals, nuclear substances, microorganisms, and other contaminants for each water basin
(i) Establishment of special pollution prevention zones for water bodies meant for drinking water supply
(j) Regulation of discharges of sewage and harmful substances

(k) Regular updating of the freely accessible State Water Register containing data on water quality and quantity, regimes of water use, water-related facilities, water protection zones and legal agreements and decisions on water use
(l) Monitoring system at the water basin level

As in 2009, the new water code was just beginning to be implemented broadly and so its impact on water management and use was still to become visible (Smith et al. 2012).

7.4.2.5 South Africa

South Africa embodied in its constitution human and ecosystem water rights and passed a comprehensive new National Water Act in 1998. The salient features are as under.

(a) A concept of 'reserve' has been introduced in which both ecological reserve (refers to a minimum level of in-stream flow to ensure ecosystem sustainability) and human reserve (refers to the quantities of water necessary to meet basic human needs) are combined. This reserve must be set aside before water is to be allocated to other uses and demands.

(b) The Act provides for:

    (i) Compulsory national water-quality and supply standards (Drinking Water Quality Regulation Program, 2005 requires standardization of microbial and chemical pollution)
    (ii) Standard water tariffs
    (iii) Efficient, affordable, economical, and sustainable access to water services
    (iv) Regulations for water service

(c) The country has been partitioned into 19 water management areas based on drainage regions, to be governed by Catchment Management Agencies having responsibilities to

    (i) Coordinate and promote public participation in water management
    (ii) Collect water-use charges
    (iii) Issue water-use licences

Till 2010, significant progress has been made in implementation of the Act. According to surveys by the World Health Organization and the United Nations Children's Fund in 2010, access to improved water supply in rural areas increased from 66 % in 1990 to 78 % in 2008; however far less progress has been made in sanitation. Though the 'Blue Drop' status—a form of award to water service providers who are at or above 95 % compliance with water-quality standards—introduced by the government improved the situation in cities, progress outside the main cities was still poor. As in 2010, all of the 150 municipal authorities had water-quality monitoring programmes in place, but only 26 of them had actually been awarded Blue Drop status (Smith et al. 2012).

7.4.2.6 Australia

Growing populations and economic demands have led to rising water diversions for agricultural and urban use resulting in increased environmental problems, decreased water quality, loss of wetlands, proliferation of toxic cyanobacteria and increased soil salinity. Severe and prolonged drought and extreme flooding have become frequent. According to a survey of 2008, during the period 1997–2006, runoff to the country's main agricultural region, the Murray-Darling Basin was 21 % lower than the historical average. The Australian Bureau of Meteorology has predicted twofold rise in the frequency of droughts in two to three decades. It was in this background that reform of the water-management system was undertaken in Australia in 2007 and the Commonwealth Water Act, 2007 came into being followed by intergovernmental agreements and an investment of approximately 13 billion Australian dollars. The highlights of this Act and the agreements are as under.

(a) Assignment of the constitutional rights over water resources in the Murray-Darling Basin by the states to the Commonwealth
(b) Federalization of water data collection
(c) Requirement of greater regulatory reporting with regard to water balances
(d) Introduction of a system of National Water Account
(e) Moving to full-cost recovery for all water infrastructure and services
(f) Creating a market for water trading (based on tradable property rights)
(g) Increasing farm efficiencies (e.g., canal lining, drip irrigation, shifting to more water-efficient crops)
(h) Purchasing water entitlements from willing sellers to restore aquatic ecosystems

During the subsequent years, the water market alone has been credited with halving water consumption, particularly in drought-prone regions like the Murray-Darling Basin. The Act also created a new federal repository of water monitoring and measurement information. These data are considered critical for adequate water-quality and water-quantity protection (Smith et al. 2012).

7.4.3 *Comparative Analysis of the International Policy Efforts*

The strengths and weaknesses of the policy efforts in the above six countries are analyzed in Table 7.6.

Table 7.6 Comparative analysis of the strengths and weaknesses of policy efforts

Parameter	India	US	European Union	Russia	South Africa	Australia
Nature of policy as in January, 2013	Only a draft umbrella framework; yet to be firmed up	Fragmented and piecemeal	In place	In place	In place	In place
Scope of policy—only surface or only groundwater or both	Both (implied, not explicitly stated)	Not specified	Both (implied, not explicitly stated)	Both comprehensively	Both (implied, not explicitly stated)	Limited to surface water only
Status of implementation of policy as in January, 2013	In draft stage	Comprehensive policy not in place	Implementation underway	Implementation begun	Implementation in full swing	Implementation in full swing
Decentralization	To political/ administrative units	Not stated	To natural river basins	To natural river basins	To natural river basins	Partly centralized and partly to political/ administrative units
Emphasis on database	No	No	No	Yes (State Water Register)	Yes (reserve)	Yes
Pricing aspects	Tariff mechanism	Not specified	Full cost recovery including environmental and social costs	Not specified	Tariff mechanism	Market-based

Environment and ecology protection goals		No	Not specified	Yes	Yes	Yes	Yes
Demand forecasting		No	Yes	Yes	No	No	Yes
Sustainability goals and strategy		No	Implicit in conservation goals and stress on technology	No	Yes (implied)	Indirectly implied	Yes
Pollution control provision	Chemical	Yes	Yes but not explicitly stated	Yes	Yes	Yes	Not explicitly stated
	Microbial	No		Yes	Yes	Yes	
	Nuclear	No		Yes	Yes	No	
Priorities		Irrigation and drinking	Conservation, innovation and technology	Not specified	Drinking	Ecosystem sustainability and human needs	Increasing firm efficiency; focus on Murray-Darling Basin (the principal agricultural region)
Regulatory mechanism		Not specified	Not specified	Yes	Yes	Yes	Yes

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Chapter 8
Sustainability and Sustainable Development of Mineral Resources

The two are different by the way they are understood. Sustainability in general is understood in the sense of security of the planet or a country and that in relation to mineral resources is linked with security of raw material availability. On the other hand, sustainable development of mineral resources denotes ways and means in which mining should be carried out and is linked to corporate social responsibility (CSR) and certain other activities with a view to developing the areas and the peoples around mines. In a sense, the former is more security-centric while the latter is more welfare-centric.

8.1 Sustainability of Mineral Resources

Security is an omnifarious term and may mean food security, raw material security and living security. In this book the focus is on mineral raw material security i.e. sustaining the availability of minerals. Worldwide, there are concerns about security of mineral raw materials to feed the fast-growing industries especially in the highly industrialized countries like European Union (EU) countries and Japan. Its technological aspects involving exploration and mining with the help of newer and newer technologies and expanding the frontiers of human reach to oceans and space with a view to extending the life indices of the mineral resources and ensuring supply of raw materials for longer periods, have been discussed earlier in this book (Chap. 3: Mineral-Human relationship). Energy security has also been discussed in Chap. 4. In this chapter various socio-economic and political aspects will be discussed from the macro-management point of view.

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8.1.1 The Backdrop

The concern for mineral raw material security has not come all of a sudden. This state of insecurity has gripped the governments across the world in the backdrop of uncontrolled growth of population, commensurate increase in demand for industrial goods, widening gap between demand and supply of raw materials and increasing pressure on the democratically elected governments to bring in parity between the haves and the have-nots. The two basic reasons are discussed as follows.

8.1.1.1 Epicurean vs Environmentalist Approaches

Epicurean ideology believes that pleasure is the end of action and it thrives on exploitation, economic profit, benefits and success at all costs which translates to more and more industrialization to satisfy the desires of the growing population. Environmentalists, on the other hand, cry for the preservation of the Earth's environment, protection of the biodiversity and reversing or slowing down of the human-induced global warming. A classic case to exemplify this conflict is the Arctic. The environmentalists view the Arctic as an antidote to global warming by virtue of the high albedo of the white snow, and its runaway melting due to global warming will accelerate the process of destruction; besides, for them the snow serves as a lid to the potent greenhouse gas methane hydrate locked up under it. To the epicurean, Arctic is rich in three kinds of resources which will become available for exploitation once the snow melts. These are:

(a) The sea lanes on the surface are opening up to commercial traffic along the northern coasts of Russia and Canada.
(b) Under the seabed there are potential oil and gas deposits that can be drilled and recovered.
(c) In the water in between, there is the planet's last un-fished ocean.

This conflict is no longer confined to the two groups, but has escalated to a state of virtual cold war amongst the epicureans over the oil and gas prospect in particular. The eight Arctic countries—Russia, Canada, US (Alaska), Norway, Sweden, Denmark (Greenland), Finland and Iceland—are now aggressively staking claims and counter claims over a share of the Arctic Sea.

From the epicurean point of view, since the population is not only increasing in size but the standard of living of the humans in terms of material consumption is also rising, there is no alternative to production of more and more goods and services and so, to increase in industrialization. The epicureans argue that it is legitimate for the low- and medium-income countries to aspire to be at par with the high-income countries and this will translate to higher and higher consumption of energy, industrial water and minerals at large accompanied by expansion in mining activities. Just taking electricity to 100 % of the population in the developing countries will result in tremendous increase in coal consumption.

Another argument is based on the difference between per capita metal consumption in the developed countries and that in the developing ones. Taking aluminium as an example, its per capita consumptions are:

Europe	30 kg
United States	25 kg
Japan	15 kg
China	3 kg
India	1.3 kg

It is legitimate for the developing countries like China and India to aspire to be at par with the developed countries or for that matter, for all the countries to raise the standard of living of their people to the level of Europeans.

The environmentalists working in the global or national spheres, on the other hand, are trying to put brakes to this runaway industrialization. Their primary concern on the global scale is to make the life on the Earth sustainable and to save the plant from warming up due to emission of greenhouse gas. The governments worldwide have made tough laws for environment protection. The chrysotile asbestos may be sited as a classic example. This variety of asbestos is characterized by very thin, flexible, hollow and tough fibres which are resistant to fire, heat, sound, electricity, chemicals and it is suitable for many useful products. But it is also carcinogenic and exposure to its fibres can also result in fatal diseases like asbestosis and pulmonary fibrosis. This resulted in a worldwide campaign followed by litigations by the affected people and eventually closure of the largest asbestos mining centre in Quebec, Canada in 1982. The company Manville Corporation had to pay heavy compensation and finally went bankrupt. This set off a chain reaction culminating in ban on mining, processing and even use of this mineral in India and many other countries.

Further, the environmentalists argue that containing industrialization also makes economic sense in the form of saving land for agriculture and other environment-friendly economic activities, improving human health etc.

8.1.1.2 Importance of Minerals to Human Life

From flint to fullerene, the history of use of minerals is long. The Stone Age humans used flint to tear and cut animal hides for protecting themselves against the glacial cold and also to make spears and axes to hunt and defend; much later, the same mineral was used to draw lines on rock surfaces and around 30,000 or so years ago, it was used to make fire. Meanwhile, the two colouring minerals ochre and hematite gained familiarity. The first mineral that came to human life after them about 8,000–10,000 years ago was clay for making utensils to cook and bricks to build shelters. As science and technology developed, the use of minerals diversified to copper, lead, tin, zinc, gold, silver, silica sand and finally to iron 3,800 years ago. Next big thing was discovery of coal. The industrial revolution in the latter half of the eighteenth century speeded up industrialization and the goods and services that the humankind had never before enjoyed, started being produced. These changes became even faster since about the middle of the twentieth century when the World War II was raging and the first atom bomb was exploded. Information technology and communication explosion followed all with the help of newer and newer minerals.

Right from the morning to night, every human uses one or the other thing based on one or more minerals. Whether it is toothpaste, or news paper or cups and plates or vehicles or viewing television or listening to radios or playing or sleeping on a bed—consciously or unconsciously they use some mineral. Today more than 3,000 minerals have been reported and named of which 1,800–2,000 have been fully studied and described; but even after hundreds of thousands of years of trials and errors, about 100–150 minerals, metals and rocks are being gainfully used. These minerals are the basic raw materials for the industries including agro-industries and even those manufacturing environment protection equipments.

Since around 1960, there has been a revolution in the field of various 'new' materials of the kinds of electronic chips, highly special glass and advanced ceramic products, the metal-matrix composites, special alloys and super-alloys, semi-conductors, laser, radar, super-conductors, components of space ships, materials for artificial human organs, nano-tubes, materials required for geoengineering and environmental hazard mitigation etc. and the researches in material science are currently going in this direction. Minerals like graphite, fullerene, helium, zeolite, quartz, micro-diamonds and metals like rare earth metals play a very important role in development of such materials.

However, throughout the history of human civilization, two mineral commodities have remained the common factor. These are the aggregates and gold which form the lowest layers of the foundation of modern economy worldwide and their sustainability have become the concern in many areas of the world. The reasons for their indispensability are elaborated below.

(a) Aggregates

These comprise clay, soil, sand and stone chips without which no construction can be possible—buildings, plants, roads, railway tracks, bridges. Throughout history their availability has been taken for granted and never considered as critical. Indeed they are not very costly to mine and can be dug and crushed. Clay can even be just scooped from the surface around brick kilns. But at the same time they are required in very large quantities. It is this factor of large scale indiscriminate and unsystematic digging of the land that has caused irreparable damage to the landscape, topography and groundwater recharge in many areas. Sand mining has damaged even rivers threatening supply of surface water during summer months. It has now drawn the attention of the environmental regulators and the Supreme Court of India which, in its order dated February 27, 2012, has made environmental impact analysis (EIA) mandatory before mining of aggregates. As a consequence to this, the state governments in India have stopped granting permits for aggregate mining. Now, in many areas of India the very availability of aggregates has become a concern and the construction of highways and other infrastructure have come to standstill (FIMI, Jan 15, 2013). In Punjab, it has even become a threat to law and order (FIMI, Jan 1, 2013). There are some emerging possibilities to substitute aggregates by materials such as flashag (sintered fly ash), syndecrete (eco-friendly concrete made from waste glass, rejected vinyl LP records etc.), grancrete (ceramic spray applied on cheap ordinary building surfaces) and ecoshake (roofing shingles made from cent per cent recycled material). But the technologies and production facilities are presently confined to a few countries and places and, unless they are locally available, they will not be of any use to the common mass.

(b) Gold

It is not known how gold came to be regarded as the most valuable metal. In the beginning (4000–6000 BC) it was valued as a precious jewel because of its unique combination of high specific gravity (i.e. high value-volume ratio), attractive appearance, indestructibility and scarcity. When trade amongst different kingdoms started, particularly maritime trade, it became convenient to carry this metal and exchange it for other goods of high value. Gradually, gold evolved to be a reference for exchange of goods. Many other metals like silver, copper and iron came and went as exchange metals in different countries; the Romans even used salt to pay salaries of the soldiers. But gold remained throughout as the only acceptable reference metal for exchange of goods internationally. After the World War II (1939–1945) the International Monetary Fund (IMF) came into being in 1948. When the IMF introduced the Breton Woods monetary system, gold was made the cornerstone and the basis for reckoning of the values of currencies of all the countries for exchange purpose and every country is required to maintain a stock of gold in their central banks which has to be declared periodically. On the amount of stock held by a country depends the exchange value of the currency of that country. The stocks held by the central banks of some important countries are as under.

United States	8,000 tonnes as on Feb 20, 2008
Germany	4,000 tonnes as on Feb 20, 2008
IMF	3,217 tonnes as on Feb 20, 2008
China	1,054 tonnes as on Dec 31, 2009
India	557.7 tonnes as on Dec 31, 2012
Saudi Arabia	323 tonnes as on Dec 31, 2010

Now, price of gold has become a cue for investment in mineral exploration. Table 8.1 shows the relationship between investment in metallic mineral exploration and gold price.

Besides, in India which is the highest consumer of gold in the world, there are huge stocks of gold maintained in households for perceived security purpose as well as due to certain prejudices. According to World Gold Council (WGC), such stocks have mounted to 20,000 tonnes as in November, 2012. There is no sign of waning of this tendency as the WGC estimated the gold demand in India to be 933 tonnes during 2011 (FIMI, Dec 15, 2013) and, according to them, the demand is almost double in the villages than in the towns (*Hitavada*, April 1, 2011). According to a survey conducted by the HDFC Bank of India in 2011, as much as 9 % of India's household savings goes for acquiring gold for the purpose of both jewellery and investment. In addition there are huge stocks of gold in the temples of India

Table 8.1 Relationship between investment for exploration of metallic mineral and gold price

Year	Global spending for exploration (billion US$)	Significant reasons for increase/decrease and gold market conditions
1997	5.2 (highest since 1989)	General trend of economic liberalization in many developing countries facilitating entry of multinational exploration/mining companies.
2002	1.9 (lowest since 1991)	General recession in gold market following sale of gold by the central banks of many European countries to pay up debt in order to fulfil Euro currency criteria.
2003	2.4	Recovery of gold market and overall economy; junior exploration companies able to raise funds; more expensive late stage exploration work (e.g., feasibility study) by major companies in ongoing exploration projects and, at the same time, turning renewed attention to earlier suspended projects; favourable changes in mineral policy in South Africa (unshackling of mineral sector from the whites).
2004	3.8	
2005	4.9	
2006	7.1	
2007	11.4[a]	Gold price was on a rising trend and its share in exploration investment was over 40 %; prices of most commodities strengthened their long-term highs.
2008	12.6	
2009	7.3	Global recession
2010	10.7	Improved prices of gold and other commodities and stable market conditions.

[a]In 2007, uranium was covered in the survey for the first time (investment in uranium exploration during 2007 was US$ 1.41 billion

accumulated through centuries mainly by virtue of donations received. In the world also, the annual demand for gold has remained high at over 3,400 tonnes during the first decade of this century despite its price ruling high. This tendency to acquire and stock more and more gold is stronger when the level of insecurity of the people and the governments is higher on account of deteriorating political conditions, weakness of US dollar (the gold-backed currency accepted worldwide for international trade) and economic recession. Hence, this metal has assumed special importance for the mineral industry and humankind.

In the annexures I and II, the minerals which are in use now and the products and processes into which they go as inputs are listed.

8.1.1.3 Increasing Political Unviability of Resource Development Projects

In a large country like India, where there is land crunch but the people are increasingly being politically conscious about their rights and the government's obligations towards them and where there is wide diversity amongst the different states and areas in many respects—political system, religion, language, culture, traditions and ritualistic practices—political viability of the mineral development projects has become an important contributory factor in raw material security. Politics goes beyond the rigid boundary of legal, economic or technological justifications of a project, but it is more about the people's perception, emotions and empathy.

A comparison between the two cases of Kiruna town in northern Sweden and Jharia town in eastern India will serve to explain this issue further.

Kiruna, referred to as the 'smart mine' of Europe, is the deepest iron ore mine in the world where the company has planned to open up a new level taking the depth to 1,364 m. Already, cracks have appeared on the surface above the underground mine and when the new level is opened in about 20–25 years, the entire Kiruna town with its 3,000 houses will be endangered. The company has already drawn up a strategy for shifting the population to a new town under development. The people there have understood the danger and also the need for expansion of the mine. Neither any anxiety nor any resistance is visible amongst them (FIMI, Dec 1, 2012).

The old town of Jharia, located in the midst of the Jharia coalfield where an underground fire is raging for over 100 years, stands in contrast. There houses in the town are already subsiding and several people have died. The company plans to redesign the mining with a view to recovering the remaining prime coking coal and the government has made arrangement for the rehabilitation of the affected people, yet they are tenaciously resisting.

The public movement and agitation against setting up of nuclear power plants (and even uranium mines) in Kudankulam and other sites in India as also in the countries like Japan, France, Germany etc. have either delayed implementation of projects or forced the governments to cancel their policies and plans. This trend is making exploitation of mineral resources increasingly more difficult. For investment in mining in a country, the Policy Potential Index or PPI (elaborated later under 6.1.2.5/Acquisition) helps the investors to gauge the political risks to a large extent, but for individual areas within a country like India there is as yet no handy tool to guide them.

The gestation period in India for taking a mineral property to production stage from the date of application for reconnaissance permit after obtaining all the statutory clearances may usually extend to 10–15 years; if there is a legal dispute, the final judicial decision may take anything up to another 15–20 years. In addition, if there are political problems centred on the mineral property, there is no limit to the time period.

8.1.2 The Options for Mineral Raw Material Security

Some options for achieving security of mineral raw materials have been tried in the past and are still relevant. These are discussed as follows.

8.1.2.1 Political/Military Control

Many wars were fought from the historical to the modern times over control of mineral resources. In the ancient times, the Romans fought many wars for acquiring control over deposits of gold, silver, mercury, iron, copper, lead, tin and salt in Spain, Portugal and England. They not only developed new mines but also restarted many closed mines in the conquered regions. During the Mediaeval period, Genoa lost control over the European salt-trade through the Mediterranean Sea to Venice in 1381 after fighting three wars (salt was an essential commodity in those times for preservation of food). During the 1870s, Spain attacked and captured Peruvian territory for the sake of guano—an essential fertilizer mineral then; but later Chile and Peru together fought what has gone down in history as the Chincha Islands War and liberated the guano-rich area. However a few years later, during 1879–1884 the same Chile fought Peru allied with Bolivia in what is known as the War of the Pacific or the Saltpetre War for saltpetre (KNO_3) which was then an important ingredient of explosives. After the war, Chile annexed saltpetre-rich territories of both Peru and Bolivia.

After the second year during the World War I (1914–1918), Britain and France were almost ruined financially, but USA could continue to maintain its financial strength by virtue primarily of its resources of some vital strategic minerals. At the end of the war, it was producing 71 % of the world's petroleum, 43 % of the world's coal and 87 % of the world's automobiles (made from iron and other metals). There had been countless invasions of India from across its border for plundering the diamond stocked in the temples and palaces. Since the 1990s, a civil war has been going on in Democratic Republic of Congo between the government forces and the rebels centred on diamond resources along the banks of the river Congo. After taking control of the resources, the rebels sold the diamond clandestinely for buying arms and ammunition. The Gulf war between US and its allies on one side and Iraq on the other in 1990 was primarily over Kuwaiti oilfield which the Iraqi forces captured earlier. And as recently as in the first decade of this century, the Arctic countries of Russia, Canada, US (Alaska), Norway, Sweden, Denmark (Greenland), Finland and Iceland were in a state of cold war waiting to stake claims over the oil-rich Arctic Sea once the fast-receding snow completely disappears thanks to the man-made global warming.

However this destructive military approach to ensure raw material security is increasingly becoming more difficult. Firstly, wars require huge resources of not only arms and ammunition but also other economic commodities like food both of which require minerals. Secondly, no country is self-sufficient in all the minerals that are needed to fight the highly sophisticated and complex wars of today. Thirdly, the resources are spent destructively with no guarantee of victory. Fourthly, the well-established institutional mechanisms of UN, IMF, World Bank etc. make wars very difficult to sustain through long durations. Fifthly, the very insecurity prevents a country to indulge in a gamble like war.

8.1.2.2 Recycling

The increasingly proliferating high-tech industries of today consume scarce metals. It is in this backdrop that recycling assumes relevance. Recycling does not directly add to the resource or reserve, but indirectly contributes to extension of the life indices of the resources/reserves. Some of the metals like aluminium, copper, lead and zinc can theoretically be recycled endlessly. But in practice their recycling rates (ratio of the annually utilized quantities of scrap and the annual production of the primary metal) depends on:

(a) Collection efficiency of scrap
(b) Nature and life cycle of the product containing the metal (varies from one year of aluminium cans to over 40 years of copper cables)
(c) Amenability to technology of recovery of metal from the scrap
(d) Environmental problems arising out of the recovery process

Technological challenges of recycling include:

1. Although recycling of copper scrap consumes 50–90 % lower energy than the energy consumed for producing primary copper, recycling process in case of some metals like aluminium is energy-intensive.
2. In some products like alloys and electronics, copper is mixed with other metals and organic and inorganic material and the recovery process is highly complex and energy intensive
3. In case of cables, the plastic sheath has to be removed by burning and that creates environmental problems.
4. Although high resistance of lead to corrosion makes it highly amenable to recycling, that used in tetraethyl lead, lead pigments and solders are not at all recyclable and is irretrievably lost.
5. Zinc is less amenable to recycling than many metals because in the electrochemical series, the common alloying metals like iron, tin, lead etc. occupy higher position than zinc and hence, in a solvent, zinc dissolves more readily than these alloying metals.
6. For recycling zinc used in galvanization of iron and steel sheets, state-of-the-art plasma furnaces are required.

The recycling rates of the metals are summarized in Table 8.2.

Table 8.2 Recyclability of metals

Global average end-of-life functional recycling (%)	Metals and metalloids
Less than 1	Scandium, lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium (all rare earth metals), lithium, beryllium, vanadium, boron, gallium, germanium, arsenic, selenium
1–10	Antimony, mercury
10–25	Ruthenium, cadmium, tungsten
25–50	Magnesium, molybdenum, iridium
+50	Aluminium, titanium, chromium, manganese, iron, cobalt, nickel, copper, zinc, niobium, rhodium, rhenium, palladium, silver, tin, platinum, gold, lead

Source: UNEP, May, 2011

Note: These evaluations do not consider metal emissions from coal power plants

Table 8.3 Recyclability of metals from global e-wastes

Metal	Recycling potential in the world from e-wastes (tonnes/year) 2015	2020
Gallium	106	160
Indium	740	970

Source: UNEP, July, 2009

An emblematic issue is about e-waste generated by electronic appliances that need a growing variety of metals to reach ever higher performance for more people every day. In India alone, 150,000 tonnes of e-waste were generated in 2006 and the annual growth has been projected at 34 %. Global e-waste generation is growing by about 40 million tonnes a year. Modern electronics contain up to 60 different elements many of which are valuable. Manufacture of mobile phones and personal computers consumes 3 % of gold and silver, 13 % of palladium and 15 % of cobalt mined worldwide each year (globally, more than one billion mobile phones were sold in 2007 up from 896 million in 2006). One tonne of scrap from discarded computers contains more gold than can be produced from 17 tonnes of gold ore; a discarded cell phone contains 5–10 times higher gold than gold ore of equivalent weight; e-waste is often 10–50 times richer in copper metal than copper ore of equal weight. It is in this scenario that the issue of e-waste management by recovering the contained metals (urban mining) has become critical. The recycling potential of gallium and indium from discarded photovoltaic panels, solar street lights and other electronic goods in the world during the years 2015 and 2020 have been projected as shown in Table 8.3.

Table 8.3 gives an idea of the growing importance and technological amenability of the recycling of e-waste in the years to come.

8.1.2.3 Substitution

Substitution is also a means to extend the life indices of the resources/reserves of minerals. Many applications rely on key raw materials that are currently very difficult, if not impossible, to substitute due to their specific physical and chemical properties. Nevertheless substitution can take place in three ways as under.

(a) Development of alternative materials in certain applications to serve certain end purpose in which case only the product is substituted while the application as well as the end purpose remains the same. For example, for steel-manufacturing sponge iron can substitute pig iron.
(b) Replacement of those applications by an equivalent technology that does not rely on the key raw materials in which case both the product and the application change without compromising with the end purpose (e.g., for the purpose of generating wind energy, ceramic high-temperature superconductors may become a substitute for permanent magnets in wind turbines which currently use neodymium and dysprosium)

(c) Partial substitution of the raw materials by some renewable or waste materials having to modify neither the processing technology nor the product (e.g. partial substitution of coal by rice husk, cashew nut shells, used tyres, old currency papers, municipal garbage and sugarcane rejects in cement manufacturing).

Substitution of any substance may take place due mainly to the factors like increase in price, change in fashion and taste of people etc. But that of a mineral is generally due to the following reasons.

Finite and non-renewable resource: Stoppage of supply of mineral is not generally the cause of its substitution globally if seen in a short time span of a few years or even a couple of centuries as has been seen from Tables 3.6 and 3.7 (reserve dynamics). Even if reserves are exhausted, the back-up resources may be explored and up-categorized to reserve. There has been only one case in the recent past. The only large economic deposit of cryolite in the world which was discovered in 1799 in Ivigtut on the west coast of Greenland was operated during the period from 1854 till 1987 when its reserves were completely exhausted (and there was no back-up resource for up-categorization) giving rise to development of synthetic cryolite based on another mineral namely fluorite. But on a national or regional scale, it can happen often. In France, the 250-year old coal mining industry came to halt on April 23, 2004 due to exhaustion of reserves/resources and the country switched over to other sources of energy like nuclear.

Fixed location: This is not of much relevance in the global perspective, but is important when considered from the national or regional point of view. For example, in Germany and in the Southern and Western parts of India there is no deposit of bituminous coal and for thermal power generation there, fuel is sourced to a somewhat inferior substitute namely lignite (brown coal) which is available in abundance.

Long gestation of exploration of mineral deposits, development of mines and establishment of processing and end-use industries: Bringing a virgin deposit starting from the stage of application for reconnaissance to the stage of production takes around 15 years in India (in other countries it may be a few years more or less) provided there is no litigation or dispute regarding land and other matters and if there is, then the period may be indefinite (in India, the local tribals have held up mining from a deposit of uranium in Meghalaya for over 30 years counted from the year when exploration began). But in the meanwhile, the processing and the end-use facilities may be ready. Under such circumstances, there may be temporary substitution by another raw material to keep the facilities running. Substitution of coal-based power by diesel generators can in certain cases be cited as an example. But normally, shortfalls of raw material supply arising out of this sort of problems are met through import in which case the substitution will be limited to indigenous mineral by imported one and considered from a global point of view, this does not carry any sense.

International relation: When demand for certain minerals or metals in a country is met through import from another country, mutual hostilities may cut off the supply and the importing country may be forced to search for substitutes. From a global standpoint, this also does not carry any sense except that some new material or process may be developed. This was the cause due to which the modern process of manufacturing pencil was developed. Graphite was discovered in 1564. For the next 250 years, Britain had the monopoly of lumpy graphite which was cut and shaped to make writing pencils. France was one of the countries which was dependent on lumpy graphite imported from Britain for pencil-making. During early nineteenth century, France under Napoleon was at war with England and supply of good grade lumpy graphite from the latter was cut off. Then at the instance of Napoleon, the technique of pencil-making was refined by Nicholas Jacque Conte. He mixed powdered graphite and clay, moulded it in the shape of thin long pieces and then burnt them in a kiln at a temperature of about 100 ° C. The same principle is still in vogue.

There are various modes by which a particular mineral may locally be substituted—by the same mineral of lower quality with the help of a different technology (coking coal by non-coking coal in iron-making); by another mineral (copper by aluminium in electrical transmission wires); by a waste product (clay bricks by fly ash brick, limestone by fly ash in cement manufacturing, coal by coal washery rejects for thermal power generation); or by a non-mineral (coal and petroleum by solar, wind and biomass energy). But there is no possibility of doing away with the non-renewable minerals altogether. Moreover, even if a renewable material is used, the technology for its processing will require non-renewable minerals.

8.1.2.4 Mine Waste and Mineral Usage Waste Utilization

Such wastes generate before, during and after extraction due to the following reasons.

(a) *Overburden:* Because of the mode of occurrence of a mineral deposit at depth under thick overburden rocks, it is necessary to first remove those rocks before exploitation of the mineral can begin. These rocks are dumped on the ground as wastes. The greater the depth more will be the quantity of such waste.
(b) *Grade of the mineral:* Even the best grade ores of high-value metals like copper, gold etc. as mined throughout the world, contain very little amounts of the metals. For instance, copper ore on an average contains 1.0 % copper metal and gold accounts for less than 2 grammes in a tonne of its ore. This means that for each tonne of copper and gold recovered 99 tonnes and nearly 500,000 tonnes of waste rocks have also to be mined respectively. Similarly, Indian coal contains on an average 30–50 % ash which, after burning, accumulates as wastes in the thermal power plants. Same holds good for all the metals and minerals. The waste rocks generated every year during production of copper, gold and aluminium are estimated to be 1.4 billion tonnes, over 1 billion tonnes and 50 million tonnes (red mud) respectively.

The issue of utilization of part of such waste rocks are being addressed in many countries including India through research, development and innovation. In Table 8.4, some common examples of such efforts are shown.

Table 8.4 Mine waste and mineral usage waste utilization

Waste product	Use
Coal usage wastes	
Carbon dioxide	Fishery, food processing, greenhouse, petroleum recovery (secondary)
Cenosphere (derivative of fly ash)	Adhesive, plastics, rubber (including synthetic rubber)
Coal dust	Metallurgy (iron), reductant
Coke breeze (coke handling waste)	Chemical, coke manufacturing, deoxidizer, foundry, pellets, sinters
Flue dust (particles associated with flue gas emission from industrial plant)	Metallurgy (germanium)
Flue gas (emission from industrial plant)	Desulpho-gypsum/flue gas desulphurization (FGD) gypsum/scrubber gypsum
Fly ash (thermal power plant waste)	Asphalt (for paving), brick (fly ash), cement, cenosphere, construction (concrete), insulation brick, land reclamation, plant nutrient, road metal/aggregate (base material), soil conditioning, stowing (mine), synthetic zeolite
Waste associated with zinc recovery process	
Cobalt cake/beta cake	Metallurgy (zinc)
Copper cake	Metallurgy (zinc)
Moore cake	Metallurgy (gold, lead, silver, zinc)
Muscovite processing waste	
Scrap mica	Glass-bonded mica, reconstituted mica
Waste associated with processing of oil shale	
Spent shale	Brick (shale-lime), cement, lime (hydraulic)
Quartz mining reject	
Lasca	Fused quartz used for making inner quartz bulbs for halogen lamps

8.1.2.5 Foreign Sourcing

There may be two ways by which a country can source its raw materials to another country—import and acquisition.

Import: This may be necessary for a country under certain circumstances as under.

(a) *Deficiency in resource of certain mineral:* If a country suffers from such deficiency it may be necessary for it to import the mineral from other countries. India imports around two-third of its requirement of crude petroleum both on long-term contract and spot purchase basis. But at times of war or strained relationship between the exporting and the importing countries this may create formidable problems. During the World War II (1939–1945) US faced serious crisis because of absence of minable reserves of a vital strategic metal namely tin which serves to can food for the thousands of soldiers fighting in the front for months together. It was importing this metal from the Far-East and the Japanese navy regularly targeted the cargo ships carrying tin for US. After the war, however, US built a huge stockpile of tin before launching the Korean War (1950–1953). This example gives an important cue. It is not enough to import for meeting day-to-day requirements, but a government must also anticipate contingencies and build stockpiles which in its turn requires some serious economic analyses as follows.

(i) The best price to purchase from international market has to be judged. This is not possible if the import is based entirely on long-term contracts.
(ii) Stockpiling requires investment of substantial funds for both purchasing and maintaining idle stocks indefinitely.
(iii) For liquid and gaseous minerals like petroleum and natural gas, special facilities for storage have to be constructed.
(iv) In the present international political setup, multiple sourcing is called for instead of depending on a single source. In the past, sanction imposed by the UN on South Africa and more recently on Myanmar debarred other countries from having any business link with them. Presently, a similar situation exists with regard to Iran on which India has been significantly depending for petroleum and natural gas.
(v) International relationship including business relation is always on the premise of give-and-take. So a country importing from another country must also export something to the same country or alternatively, pay in either gold or some international currency like dollar, sterling pound or euro.
(vi) The importing country may have to offer some favourable conditions to encourage foreign investors to invest in exploration, mining, manufacturing etc. The conditions may include low royalty, cheap land, easy repatriation of profits or a receptive consumer base.

It is obvious that a country possessing no mineral resource or nothing else to offer may find it extremely difficult to prosper.

(b) *Availability of enough resource:* A country may keep its resources idle for meeting crisis situations in future while resorting to import to meet present demand. This may be as a strategy or under compulsion due to some formidable hurdle. US deliberately kept its oil shale resources unexploited and instead resorted to import of oil to meet the domestic demand. On the other hand, in spite of abundant reserves of both coal and iron ore, India is now importing them because of environmental and social hurdles coming in the way of their exploitation.

Acquisition of mineral property: The criteria of investment have now gone beyond economic outcome to redressal of environmental and socio-political problems. Consequently, launching a mining project in virgin areas in some countries (e.g. India) is increasingly becoming harder, more time-consuming and more expensive. If the governmental policies in another country are investor-friendly, then it is easier for such companies to take the acquisition route in a foreign country than taking up greenfield mining projects in the parent country. There are three modalities as under.

(a) Acquisition of a mining company
(b) Merger with another mining company
(c) Acquisition of a virgin mineral property

The reasons can be summed up as below.

(a) Anxiety in the industries regarding shortage of mineral raw materials in the short run
(b) Availability of surplus cash with the companies due to high metal prices (mainly due to increased demand from China)
(c) Motivation for achieving supply security
(d) Management of price volatility by a metal company through backward integration with a mining company
(e) Competitive advantage in bidding for end-use projects

But this route of sourcing minerals to foreign countries is fraught with some risks. Even after more than twenty years of liberalization and globalization of economy across the world, unbridled opportunity to develop the mineral resources by any investor in any country has not become visible. The governments and the societies of many countries view their finite, non-renewable and hidden mineral resources as precious treasures endowed by nature. In an atmosphere of supply crunch and insecurity, countries are more and more becoming wary of letting go their minerals. Policies like export restriction, value addition within the country, compulsory technology transfer, mandatory condition of partnership with locals, higher taxes on minerals, sharing of mined minerals with the local government etc. are increasingly becoming the order of the day. The constraint can be summed up as follows.

(a) Risk of socio-political climate of the foreign country suddenly turning hostile due to change of regime
(b) Expropriation by the foreign government at a later year (e.g. nationalization of oilfields in Middle-East countries)—rated by the global credit rating agency Earnst & Young (E&Y) as the highest risk in 2012 and the third highest in 2013
(c) Impact of political developments on tax environment
(d) Fluctuation of foreign exchange rate
(e) Restrictions on freedom of management
(f) Conflicts between goals of a foreign investor and goals of the local governments and political forces
(g) The government's perceptions of the company's impact on local economy
(h) Infringement on national sovereignty and control of natural resources
(i) Impact on other industries
(j) Limitations imposed by the local government on transfer of funds and dividends
(k) Resource nationalism
(l) Inability to understand local mafia and political agenda of the local politicians
(m) Access to capital (rated by E&Y as the highest risk in 2013) (FIMI, July 15, 2013)

Over and above this kind of restrictive policies, there is the issue of stability of both governments and policies. A mineral development project starting from application for reconnaissance permit to final closure of mine may usually last through several decades and the chance of governmental policies remaining stable throughout this period weigh heavily in the minds of the investors, particularly the multinational companies intending to invest in a foreign country. The degree of sensitivity of investment to policy changes is best exemplified by what happened in South Africa, India, Australia and Indonesia in recent times. In South Africa, due to transfer of mineral rights from the whites to the State in 2003, exploration expenditure increased by more than 46 % compared to 2002. In India, restriction on sale of coal by private mine-owners continues to be a formidable disincentive for investment in its exploration and mining by foreign investors. The new government of Australia, which has come to power in 2011, has imposed a heavy resource rent tax (RRT) of 40 % on the value of iron ore and coal mined resulting in a slump in investment in these mining sectors. The Indonesian Government started mulling over compulsory value addition to coal of grade below 5700 kcal/kg adb (air-dried basis); this would affect even those mining contracts which have already taken effect. Mere report of a proposal before the Government dampened the investment climate significantly.

The most important tool relied upon by multinational companies for zeroing on in the most suitable country for investment is the Policy Potential Index (PPI) of the Fraser Institute. This index is based on the replies circulated to important exploration, development and mining companies around the world asking them to assign score on a scale of 1–5 in decreasing order of investment friendliness only in respect of the jurisdictions and factors with which they are familiar with. The survey broadly takes into account the following factors:

1. Regulations and their administration and the associated uncertainty
2. Environmental regulations
3. Taxation regime
4. Problems of acquisition and other matters related to land (e.g. native land claims)
5. Infrastructure
6. Socioeconomics
7. Political stability
8. Labour laws
9. Geological database (including quality and scale of maps and ease of access to information)
10. Security

The responses are analyzed to assign a final score out of 100 to each jurisdiction (a country or a state in US, Canada and Australia) and to report its rank in the survey year. The Policy Potential Index refers to this final score. In 2012, out of the 96 jurisdictions ranked according to PPI, Indonesia was the last because, mainly, two major policy changes—ban on export of raw materials and compulsory divestment of majority shares to local entities (FIMI Newa, April 1, 2013).

Besides, the investors also bank their decisions on the ratings of different globally trusted credit-rating agencies like Moody's, Earnst & Young, Standard & Poor etc.

8.2 Sustainable Development of Mineral Resources

8.2.1 Concept and Key Factors

In a generalized sense, sustainable development means development and improvements in standards of living without impairing the future ability of the environment to provide sustenance and life support to a population. This concept took root for the first time in the report of the World Commission on Environment and Development (popularly known as Brundtland Commission) of 1987 which defined sustainable development as "ensuring to meet the needs of the present without compromising the ability of future generations to meet their own needs" (Chatterjee 2008; Nanda 2012) and subsequently, it was discussed in the global conference held in Rio-de-Janeiro, Brazil in 1992 under the aegis of the UN Conference on Environment & Development (UNEDP). This concept underwent modification and in 1999 the Ministry of Environment & Forest (MoEF) of India in its report 'State of the Environment' defined sustainable development as 'ensuring that maximum rate of resource consumption and waste discharge for a selected development portfolio would be sustained indefinitely, in a defined planning region, without progressively impairing its bio-productivity and ecological integrity'. However, these definitions were in the context of general development. In relation to the mining sector in particular, certain key elements determining a sustainable mining operation have evolved (MOM 2012). These are:

(a) Financial viability
(b) Socially responsibility (operations creating social and economic wealth which will outlast the life of the mine)
(c) Environmental soundness
(d) Technical and scientific soundness
(e) Long-term view of development (mine closure, land restoration, rehabilitation of workers)
(f) Optimal use of minerals
(g) Sustainable post-closure land uses

The factors due to which it has become imperative for the Indian mining sector to implement sustainable mining are as follows.

(a) To a great extent minerals, forests and tribals are concentrated in the same geographical areas.
(b) Traditionally, the attitude of mining companies had been short sighted and unethical with the sole motive to earn maximum profit in minimum time.

(c) The continuous negligence of the local area and the local people made them suspicious and hostile towards mining operations.
(d) Resource curse i.e. the mineral-rich areas are counted amongst the poorest areas.
(e) The long-pending and pernicious resettlement issues have contributed to anti-mining attitudes in such a degree that it has become impossible for a mining operation to start in time.
(f) The reluctance of a large section of mining companies to embark on cost-increasing activities like preservation of land, environment and biodiversity and also social rehabilitation of the displaced people has contributed to this no-win situation.
(g) Two laws namely the Panchayati Raj (Extension to the Scheduled Areas) Act, 1996 and the Scheduled Tribes & Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 are now addressing such issues. The former makes it mandatory to obtain prior recommendation of Gram Sabha (village council) before granting of prospecting licence or mining lease in Scheduled areas; while the latter recognizes the traditional individual and community rights of people living and using the forest and stipulates that these rights should first be settled before acquisition of land for a mining project.
(h) Besides, a Supreme Court judgement of 1997 commonly known as Samatha Judgement prohibits mining in Schedule V areas (tribal dominated areas) without the participation of the local people.

Although the concept of sustainable development is widely accepted, yet the implementation of sustainable development has not moved beyond some slow and incremental steps for transformative action. The major bottlenecks have been identified (Nandi 2012) as:

(a) Lack of leadership
(b) Tendency of each sector to wait on the other to take the initiative.
(c) Lack of financial and technological resource
(d) Inadequate infrastructure
(e) Poor quality of governance

Nevertheless, under pressure of environmental activists and resistance of local people against mining projects, both the government and the industries of India are now slowly realizing the gravity of the situation and urgency of action.

8.2.2 Sustainable Development Indicators

In a programme organized in India during 1999–2000 jointly by the UN Development Programme (UNDP), the Ministry of Environment & Forest (MoEF) of India and the International Development Research Centre (IDRC) of Canada, a set of national indicators was arrived at. Later on, US Government also made some additions. These indicators were broadly grouped as follows.

(a) Environmental indicators (e.g. groundwater reserve, waste water treatment, industrial and municipal discharge, rate of depletion of mineral resources, harmful emissions, use of agricultural pesticides, rate of erosion of top soil etc.)
(b) Economic indicators (e.g. GDP growth, gross export and import, mineral reserves, energy consumption, job and income distribution etc.)
(c) Social indicators (unemployment rate, poverty ratio, male-female ratio, fertility rate, infant mortality, incidence of environment-related diseases, adult literacy rate etc.)
(d) Institutional indicators (programmes and strategies, national environmental statistics and indicators of sustainable development)

However, these indicators are in the context of general development. In India, certain measurable parameters of sustainable development specific to the mining areas are under consideration of the Government (MOM 2012). Emphasis has particularly been laid on the following indicators.

(a) Ensuring minimal adverse impact on the quality of life of the local communities
(b) Protection of the interests of the affected people
(c) Creation of new opportunities for sustainable livelihood in the local area
(d) Mineral conservation
(e) Reduction in waste generation
(f) Minimizing and mitigating adverse environmental impacts on surface and ground water, air, ambient noise and land
(g) Ensuring minimal ecological disturbance in terms of biodiversity, flora, fauna and habitat
(h) Promoting restoration and reclamation of mined out land for the benefit of the local communities
(i) Consultative mechanism with stakeholder groups and formulation of measurable indicators at the local area level
(j) Public disclosure of the indicators to facilitate sustainability audits

This is a framework approach implying that it is a flexible one that allows the achievement of sustainable development objectives without being too prescriptive and formulaic. The monitoring agency may use its discretion to fix standards.

8.2.3 Corporate Social Responsibility (CSR)

The line dividing the CSR and the sustainable development is indeed very thin. CSR is a concept whereby companies serve the interests of society by taking responsibility for the impact of their activities on communities and the environment; and it is a company's commitment to operate in an economically, socially and environmentally sustainable manner. The only difference between CSR and sustainable development is that the former is company-specific while the latter is area-specific. In other words, a company may be located far away from its activity centre and it may carry out welfare activities anywhere in the country but sustainable development takes place in and around the area of the activity. If, however, the company and its activity are located in the same area, the difference disappears. In fact, CSR extends beyond philanthropic activities and reaches out to the integration of social and business goals of a company.

In India, CSR is mandatory in the Companies Act, 2012 while sustainable development in the Mines and Minerals (Development & Regulation) Bill (MMDR bill), 2011 (under consideration of the Parliament as in August, 2013). The Companies Act is loaded with financial commitments by the industries commensurate with their networth, profits and turnover solely for CSR-related activities while a framework for sustainable development is a part of the proposed MMDR bill.

The activities under CSR in an area prescribed by the Department of Public Enterprises, Government of India which are especially relevant to mining companies include creation of infrastructure in the surrounding villages for communication, health care, sanitation, education, drinking water; development of pisciculture, social forestry etc.; encouragement of sports, art, culture and literature; promotion of alternative livelihood means; setting up of skill and entrepreneurship development centres; development of unconventional energy sources; scholarships to meritorious students belonging to the weaker sections etc. In this prescription environment conservation does not find place unlike sustainable development framework. In fact, it represents a part of the latter.

Apparently, CSR may mean additional cost; but in reality, it is a cost in the short run and benefit in the long run. The time and cost overruns of projects resulting from the social conflicts may be reduced causing business benefits. According to a survey conducted by McKinsey Quarterly, 76 % of the executives saw it as a positive contribution to shareholder value. This becomes possible due to enhancement of a company's image in the market.

Theoretically, CSR does not extend beyond the tenure of the lease. But the International Council on Mining & Metals (ICMM) has devised guidelines for integrated mine closure. The ICMM has highlighted that the physical activities needed to close down a mine are relatively straightforward, but the greater challenge involves leaving a social and environmental legacy that operators, governments and communities can be proud of. Now-a-days, some companies are turning this obligation into business opportunities by transforming closed mines to commercial ventures like water parks, fish farming, agriculture, horticulture, forestry etc. in case of opencast mines and mushroom cultivation, underground storage of beverages, oil and water etc. in case of underground mines. Besides, there are already a couple of instances of mine tourism (700-year old Wieliczka rock salt mine near Krakow in Poland, Khewra salt mine in Pakistan and Gold Reef City Theme park in South Africa). Thus the twin purpose of providing jobs along with resource generation for the society and realizing value for the company can be served. This makes business sense in the emerging scenario of stiffer and stiffer market competition.

8.2.4 Industrial Ethics

Ethics has become a buzzword today and it goes together with responsible business practices. In case of professions like medical, architectural and legal practices, the concerned association/council prescribes and enforces codes of ethics. In case of industries, some associations/societies prescribe such codes which go together with good corporate governance that go beyond legal compliance. For the individual professionals, the American Society for Quality has prescribed the professional and engineering codes mainly in terms of:

(a) Upholding honour, prestige and dignity of the profession
(b) Advancement of human welfare
(c) Dealing with public in a modest and dignified way
(d) Loyalty to one's organization
(e) Frankness in explaining the pros and cons of any professional judgement
(f) Giving credit where it is due
(g) Holding safety and welfare of the public as paramount
(h) Fairness in competition against others

Besides, the Toronto Resolution (1993) has advocated against any prejudice with respect to sex, religion, nationality, ethnicity, age, colour or physical/mental disability and also against any threat of violation of the human rights (Helshel 2004).

Insofar as mining ethics are concerned, the idea has not taken roots. However, two infamous instances of unethical practice made some significant impact in the latter half of the twentieth century.

The first instance is about what is known as Poseidon scandal. Poseidon had been operating Windarra nickel prospect in Australia. On Oct 1, 1969, before the start of trading in the Adelaide Stock Exchange, the directors issued a historic report showing an abnormally high value of 3.56 % of NiS with the result that the stocks of the company shot up. Later on it was found that Poseidon had no basis on which to make such a calculation at the time and the actual assay of the core turned out to be substantially lower. The second instance is about the Canadian exploration company called BreX which explored in the Busang gold prospect in Indonesia in 1994. It reported a high value of 6,200 tonnes of gold metal reserve (8 % of the world reserve at that time) resulting in a boom in its rating in the stock market; but in 1997 it turned out to be a fraud after revelations that the geologist concerned mixed specks of gold to inflate the assay value and actually, there was no gold.

These scandals resulted in the Joint Ore Reserve Committee (JORC) Codes for reporting of exploration results first in 1981 followed by periodical revisions. It subsequently served as the mother of several systems of reporting around the world. The JORC Code emphasizes on transparency and materiality of the reports that must be signed by 'competent persons'. It has defined a competent person, inter alia, as one who is a member of an internationally recognized professional council/society/association which has a system of verifying the credentials of its members and prescribes a set of codes for them to adhere to (e.g. Australasian Institute of

Mining & Metallurgy; Minerals Council of Australia; and Australian Institute of Geoscientists). The Institute of Materials, Minerals & Mining (IMMM) of UK has made the definition of 'Competent Person' more stringent inasmuch as the recognized professional body must have enforceable Rules of Conduct. The reports prepared under these codes are recognized by the stock exchanges worldwide and so enable companies to access to funds for investment (Chatterjee 2010).

It is obvious that the need for ethical business practices and a strong sense of corporate responsibility among mining companies that go beyond legalities cannot be overemphasized. In today's competitive and choosy market a track record of ethical practices (along with CSR) go a long way in making business sense. But in India, the associations, societies etc. which are concerned with the mining companies as well as with the geoscience and mining professionals have not yet come of age. Consequently, ethics as a formal corporate policy is still not practised here save by a few companies.

8.2.5 Human Health

The UN Conference on Sustainable Development has, in the 'Rio+20' conference held in Rio-de-Janeiro in 2012, recognized health as a precondition for an outcome of sustainable development (*Hitavada*, June 29). While this is in a global perspective, human health in mining areas is a concern calling for sustained monitoring and redressal. Diseases suffered by the workers and the local people due to factors associated with mining and processing operations are common. The factors are as follows.

(a) Noise and vibration: A section of the workers are exposed to two major types of vibrations—the whole body vibrations (WBV) of the heavy vehicle drivers and the hand arm vibrations (HAV) of the operators of hand drills, jack hammers etc. Such vibrations and more than 80 dB noise caused by vehicular traffic, and various types of machinery tend to cause hearing deficiency, nervous disorders and psychological problems.

(b) Minerals and solid mine waste: Cancer of the lungs, bronchus, alimentary tract and kidneys (asbestosis, pulmonary fibrosis, mesothelioma, silicosis and pneumoconiosis) are associated with asbestos mining and processing; silicosis with silica mining and likewise.

(c) Effluents from mining and processing plants: These plants, in many cases, are located within the mining areas for reasons of economy. Depending on the mineral mined and the reagents used for processing, various toxic chemicals can get into the effluents. Their permissible limits are as shown in Table 8.5.

(d) Ambient air: The concentration of a pollutant in the ambient air is measured in India by taking discrete measurements through a period of 8 h and taking the weighted average of those values. On this basis, the permissible limits of the various pollutants emanated in Indian mines are as shown in Table 8.6.

Table 8.5 Health effect of toxic substances from mining/processing effluents

Toxic substance	Source of effluents (mining/processing unless otherwise stated)	Permissible limit of concentration (mg/l)	Associated health problem
Cyanide	Iron ore, manganese ore and lead-zinc ore; gold ore (processing)	0.2	Deadly poison
Fluoride	Limestone and dolomite (mining)	1.5	Dental and bone diseases
Dissolved phosphates	Iron ore and manganese ore	5.0	Gastrointestinal irritation, liver damage, bone necrosis and blood diarrhoea
Hexavalent chromium	Chromite	0.5	Carcinogenic (even the products made of such chromite)
Cobalt	Chromite and lead-zinc ore	0.9	Carcinogenic
Nickel	Chromite, iron ore and manganese ore	0.5	Carcinogenic and respiratory problems
Manganese metal	Chromite, iron ore, manganese ore, limestone and dolomite	0.5	Nervous disorder
Magnesium metal	Chromite, limestone and dolomite	100	Laxative
Lead metal	Copper and lead-zinc ores	0.5	Carcinogenic, nervous disorder
Copper metal	Copper and lead-zinc ores	3.0	Liver-damaging
Barium metal	Copper ore	1.0	Carcinogenic and respiratory problems
Mercury	Coal, iron ore and manganese ore	0.01	Kidney disease and nervous disorder
Zinc metal	Lead-zinc ore	5.0	Gastro-enteritis
Cadmium metal	Lead-zinc ore	2.0	Carcinogenic and cardio-vascular disease
Arsenic	Lead-zinc ore	0.2	Carcinogenic, nervous disorder, affects muscles
Iron metal	Copper ore, iron ore, manganese ore, limestone, dolomite and lead-zinc ore	5.0	Cardiac disease
Calcium	Limestone and dolomite	200	Hypercalcemia, hyperparathyroidism, anorexia, nausea, vomiting, constipation, abdominal pain, muscle weakness, bone pain

Source: IBM (2001)

Table 8.6 Health effect of toxic substances in the ambient air of mines

Pollutant	Source mine of pollutant	Permissible limit of the concentration in ambient air (mg/m^3)	Harmful effects beyond permissible limit
Suspended particulate matter (SPM)	Chromite, copper ore, iron ore, manganese ore, lead-zinc ore, limestone and dolomite	700	Toxic mist, chronic non-specific diseases, soil degradation
Respirable particulate matter (RPM) of –10 μm size	Chromite, copper ore, iron ore, manganese ore, lead-zinc ore, limestone and dolomite	350	Respiratory problems; may affect lung tissues leading to cancer
SO_2	Chromite, copper ore, iron ore, manganese ore, lead-zinc ore, limestone and dolomite	5	Acid rain
NO_2	Chromite, copper ore, iron ore, manganese ore, lead-zinc ore, limestone and dolomite	6	Bronchitis; photo-oxidation affecting vegetation
CO	Chromite, copper ore, iron ore, manganese ore, lead-zinc ore, limestone and dolomite	40	Respiratory problems
Chromium	Chromite	0.5	Carcinogenic
Hexavalent chromium	Chromite	0.05	Carcinogenic
Nickel	Chromite, copper ore	1.0	Respiratory problems; carcinogenic
Cobalt	Copper ore, lead-zinc ore	0.05	Carcinogenic
Arsenic	Copper ore, lead-zinc ore	0.2	Carcinogenic
Copper	Copper ore, lead-zinc ore	1.0	Carcinogenic
Manganese ore	Iron ore, manganese ore	2.5	Nervous disorder
Lead	Lead-zinc ore	0.1	Excretion of porphyrins; haemoglobin in urine; affects children's brain
Zinc	Lead-zinc ore	5.0	Cough; dyspnoea; increased sweating; affects pancreas
Cadmium	Lead-zinc ore	0.05	Cardiovascular diseases, hypertension

Source: IBM (2001)

8.3 Human Resource Development

It is as an outcome of the interaction between human and mineral resources that all the objects of everyday use are produced. Mining schools were in existence in US and UK in the beginning of the sixteenth century. During the latter half of that century, study of geology as a separate discipline was introduced in those schools. But until the last quarter of the twentieth century, the main emphasis on education in these disciplines had been on techniques and technologies to maximize production of minerals and safety of the workers had been a necessity for achieving that end. Only towards the end of the twentieth century, conservation of mineral resources and environment for the future became associated with the geoscience and mining education in many countries.

Now-a-days, exploration and mining companies are no longer preoccupied with economic outcome alone, but social and environmental issues are now equally at the forefront. Consequently, there is now more emphasis on community relations, environmental attitudes and contact with non-government organizations (NGOs) with the same professionalism that the industry brings into other aspects of its business. In this era of globalized economy when transnational companies are investing for exploration and mining in the remote areas of foreign countries, there is an increasing trend on their part to specify (in addition to the usual ones like qualifications etc.) the following criteria for employment:

(a) Abilities to liaise, negotiate and manage relationship with local communities, NGOs, politicians etc.
(b) Leadership skill
(c) Knowledge of local languages

But the geoscience and mining education in the world has not yet caught up with these trends. The demands on the professionals are still rising with the present trend of incorporating sustainable development and political viability within the ambit of mining feasibility studies. To meet the challenges of raw material insecurity, the skill levels of geoscience and mining professional should be raised above the conventional education to awareness of the futuristic technologies involving application of robotics, 4-D modelling in both drilling and mining, deep ocean mining and space mining. To sum up, the mindset of the professionals will need to be reoriented towards commercial and innovative approach.

There is another alarming problem—the negativity in the movement of the demographic profile within the mining engineering community particularly in Europe where a study was conducted by the European Commission in 2007 on the competitiveness of the non-energy extractive industry in the EU. The study brought to light a looming scenario in Europe before 2020. According to that study, 'significant percentage of the present generation of the professionals is likely to retire over the next 5–10 years and there will be a massive generation gap in this sector due to decades lost in mining-related education and research resulting in shortage of engineers and scientists to take over'. A human resource mapping study conducted by an industry association of India has found that the Indian mining industry is facing shortage of 2,500–3,000 engineers every year and the situation is set to worsen in future (MEAI, March, 2013). Comprehensive and systematic study in other countries may reveal similar trends. It is needless to say, without a continuous stream of professionals in the fields of geoscience and mining with up-to-date expertise in keeping with the time, neither sustainability of mineral supply nor sustainable development of mineral resources is possible.

8.4 Governmental Role

All activities including those in the mineral sector in a country emanate from the policies of a government. There are at least four policies with which the activities in the mineral sector are closely concerned. These are as under.

- Mineral policy
- Environment policy
- Fiscal policy
- Foreign policy

A national policy reflects the will and need of the people as a whole and is the result of a consensus amongst all the stake-holders. A national policy once declared is expected to provide guidelines, national goal and direction pertaining to the concerned activities throughout the country at all levels for a considerable period of time. A stable national policy projects a stable image and ensures higher credit rating of the country amongst international investors and participants. But a government's role does not end in framing and announcing a national policy. It has to be followed up by other measures as follows.

(a) Normally, a policy by itself does not translate into action on the ground and a set of laws comprising Acts and Rules is necessary to give effect to the policy. Obviously, the Acts and the Rules pertaining to an activity are expected to be in conformity with the national policy. In India, the principal Act to give effect to the National Mineral Policy is the Mines and Minerals (Development & Regulation) Act or MMDR Act. Here, although the policy was announced in 2008, the Act has not been enacted even in August, 2013. Such time lag, needless to say, does not go well to send the right signal to the investors.
(b) There are tax laws in India and other countries which serve as useful tools to encourage or discourage exploration and mining activities. Most countries regard these activities as sources of revenue, but there are many countries which recognize the high-risk nature of investment in these activities and extend some fiscal incentives. These are as follows.

1. India
   - A mechanism of tax concession/exemption for corporate/income tax on expenditure on account of prospecting/exploration, acquisition of know-how and scientific research
   - Depreciation of book values of buildings, machinery, commercial vehicles, environmental protection and energy-saving equipments, tubes and safety lamps
   - Tax holiday for investment in backward areas
2. Canada
   - Resource allowance to encourage processing of and value addition to minerals
   - Processing allowance granted to processing operations
3. China
   - Foreign reinvestment allowance with a view to encouraging foreign investors to reinvest their profits in China itself
4. UK
   - Exemption of 'climate change levy' for the green energy production
5. Germany
   - Grant of subsidy to green energy producers

Besides, there are some legislative incentives for exploration and mining in India by foreign investors in the form of foreign direct investment policy. However, royalty is universally charged on the minerals produced. This is primarily to compensate the state for permanent depletion of its mineral resources.

But a fiscal policy goes beyond the taxes and incentives. It also gives expression to a government's attitude towards development of domestic mineral resources and lays down models for its implementation—private sector, public sector, public-private partnership (PPP) etc. It also tells whether indigenously produced minerals will be given protection against imported ones or whether they will have to compete on level playing fields.

(c) It is the governments' responsibility to create the right conditions for generation of 'critical mass' (see glossary) to bring constructive public pressure on the mining companies to practise sustainable development in mining.

(d) As regards international agreements for increasing mineral supply, the onus is on the government to maintain congenial international relation. To cite an example, India's nuclear agreement with US in 2008 followed on from another agreement with the International Atomic Energy Agency. Governments of many countries engage professional lobbyists to carry out sustained lobbying with powers-that-be in other countries.

(e) It is for a government to visualize future scenarios in respect of both developing technologies and emerging international equations. The ongoing case of Sino-Japan conflict over the Pacific island Senkaku (as the Japanese call it) or Diaoyu (as the Chinese call it) can be cited as an example. The island is tiny and mostly uninhabited. But its owner will get sovereign rights over the Exclusive Economic Zone (EEZ) in the sea around it, believed to be rich in oil and other mineral resources. Now, China has 95 % of the world's known rare earth (RE) metal resources and accounts for 90 % of their world production. Japan's high-tech electronic industry is entirely dependent on such metals imported from China. The two situations are apparently unconnected. But as a response to Japan's persistent claim to the island, China has cut export of RE metals to Japan by half and is threatening to cut more. When Japan was desperately looking for an alternative source, the Government of India has extended invitation to it to bring capital and technology to exploit the low-grade RE metals deposit located in the east coast of Orissa state, which the Japanese government has gladly accepted (that deposit was mined by the Indian Rare Earths Limited till 2004 when it abandoned it due to high cost of mining). This example demonstrates how the governments around the world have to maintain a highly efficient international intelligence network and remain vigilant to opportunities created due to international conflicts. (TOI, Bhubaneswar, Oct 3, 2012)

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Chapter 9
Annexure I: Repertory of Product-Wise Uses of Metals, Minerals and Rocks

Product/process	Metals/minerals/rocks used
Abrasive/grinding (wheel, paper, cloth)	Alumina, Aluminium hydroxide (includes activated alumina), Bauxite, Bentonite, Corundum, Cryolite, Diamond (industrial), Diatomite, Feldspar, Limestone, Magnesite, Perlite, Quartz, Seeded aluminium hydroxide gel, Silicon carbide (carborandum), Titanium, Zircon/zirconia
Acoustics	*See* insulator (sound)
Acid filtration	Asbestos (actinolite)
Acid manufacturing	Sulphuric acid (pyrites- and sulphur-based product)
Acid tank	Lead
Acrylic	Propylene, Sodium aluminate (bauxite-based chemical), Synthetic zeolite
Actinides extraction	Alumina (electrically insulating)
Activated carbon	Coal
Adhesive	Aluminium hydroxide (includes activated alumina), Attapulgite/fuller's earth, Barytes, Calcite, Chalk, Crushed stone (slate powder), Dolomite, Graphite, Gypsum, Kaolin (china clay), Lead compounds (oxides—PbO, PbO_2 and Pb_3O_4), Limestone, Potash group (potassium phosphate), Potassium dichromate (chromite-based chemical), Rutile- and anatase-based product (titanium dioxide), Silica flour (quartz—industrial variety), Silicon nitride, Sulphur, Water glass/liquid glass/sodium silicate, Wollastonite
Admiralty bronze	*See* 'gun metal'
Aero-gel/aero-sil/silica aerogel	Tetra-methyl ortho-silicate (silicon compound)
Aerosol	Fluorine-based compound (chlorofluorocarbon); Molybdenum chemical (disulphide)
Aggregate	*See* 'construction'
Agriculture/horticulture	Borax, Diatomite, Dunite, Magnesite, Perlite (expanded and milled)/Carlita/Dicalite, Pyroxenite, Rock salt, Saltpetre (Chile or nitratine or soda nitre), Shirasu (volcanic eject), Vermiculite, Zeolite

(continued)

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Product/process	Metals/minerals/rocks used
Air conditioner	Fluorine-based compound (chlorofluorocarbon), Lithium bromide (lithium-based product); Lithium chloride (lithium-based product)
Aircraft (including control system)	ALON (aluminium oxy-nitride), Aluminium, Beryllium, Boron, Fullerene (manufactured graphite), Gallium (alloys), Magnesium, Monel metal, Muscovite mica (block/film/sheet), Phlogopite mica, Selenium, Silicone (elastomer/silicon rubber), Silver, Tantalum oxide, Tin-based chemical (stannic oxide), Titanium, Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38), Weldite (aluminium-lithium alloy), Zirconium
Alcohol (ethyl alcohol)	Ethylene/olefine
Alloy (based on industrial minerals)	Graphite, Muscovite mica, Phosphorite, Phosphorus (red and yellow), Quartz (silicon)
Alloy (non-ferrous metals)	Beryllium, Copper, Manganese
Alloy steel	Ferrochrome (including charge chrome and high-, medium- and low-carbon ferrochrome, silico-chrome), Ferromanganese, Silicomanganese
Alnico	Aluminium, Cobalt, Iron, Nickel
ALON (aluminium oxy-nitride)	Aluminium
Alum manufacturing	Bauxite, Sulphuric acid (pyrites- and sulphur-based product)
Alumina	Bauxite
Alumina (electrically insulating)	Aluminium nitrate mono-hydrate (alumina-based chemical)
Aluminium carboxylate	Bauxite
Aluminium chloride	Bauxite
Aluminium foam	Aluminium
Aluminium hydroxide	Bauxite
Aluminium hydroxide gel	Aluminium sulphate—iron-free (aluminium hydroxide-based chemical)
Aluminium powder	Aluminium
Aluminium silicate fibre	Aluminium fluoride (alumina-based chemical)
Aluminium sulphate (ferric)	Bauxite
Aluminium-mica alloy	Aluminium, Muscovite mica (ground/micronized)
Aluminothermic smelting process	Aluminium powder
Ammonia extraction, fixing, synthesis	Coal, Lignite, Sulphuric acid (pyrites- and sulphur-based product), Vanadium-based chemical (vanadium pentoxide)
Ammunition/bombs	Phosphorus

(continued)

Product/process	Metals/minerals/rocks used
Analytical chemistry (borax-bead test, DNA analysis, metal bead test, reagent, enzymes called 'nitrogenase')	Borax, Borax-based chemicals (sodium borate and sodium organo-borate or liquibor), Chromic acid (chromite-based chemical), Hydrogen sulphide (sulphur-based product), Lithium borate, Molybdenum, Molybdenum chemical (ammonium molybdate), Platinum (platinum group of metal), Sodium ammonium hydrogen phosphate (phosphoric acid-based product)
Aniline (organic chemical) extraction	Coal
Animal/poultry feed	Ball clay, Bentonite, Diatomite, Lignite, Magnesite, Pyrolusite-based chemicals (manganese carbonate, manganese monoxide), Phosphorite, Rock salt, Zeolite
Annealing	Petroleum gas (including liquefied petroleum gas or LPG), Vermiculite
Anodizing	Chromic acid (chromite-based chemical)
Anthracene oil (organic chemical) extraction	Coal, lignite
Anti-freeze	Methanol (methane-based product), Potash group (potassium phosphate)
Antiknock additive	Benzene, Ferrocene, Pyrolusite-based chemical (methyl cyclo-pentadienyl manganese carbonyl), Tetraethyl lead
Antiseptic	*See* 'medical application'
Anti-skid	Feldspar, Fluorite-based product (hydrofluoric acid), Garnet
Architectural works (door frames, flooring tiles, monuments, roofing tiles, temples, tombstones, wall tiles, window sills etc.)	Dimension stones (commercial granite, commercial limestone, commercial marble, commercial sandstone, commercial slate)
Arc lighting	Rare earth metal (cerium)
Aromatic fluorides	Potassium fluoride
Art work (carvings, model-making, sculpturing, statuary)	Dimension stones (commercial granite, commercial marble), Gypsum (alabaster), Ozokerite/ceresin, Pyrophyllite, Silicone (silli-putty), Wax/paraffin wax (*See also* 'decoration')
Artifact	*See* 'decoration'
Artificial/synthetic diamond manufacturing	Aluminium, Copper (copper cup for skull melting); Garnet, Rare earth metal (yttrium), Strontium titanate, Synthetic rutile, Zircon/zirconia
Artificial gem	*See* synthetic/artificial gem
Asbestos paper	Asbestos
Ashlars	Dimension stones (commercial granite, commercial limestone, commercial marble, commercial sandstone, commercial slate)
Asphalt/bitumen/pitch/tar/coal tar	Asbestos (actinolite, chrysotile, tremolite), Coal, Crushed stone (slate powder), Lignite, Petroleum including heavy crude oil and oil shale (refinery product, heavy end), Slaked lime (lime-based product), Sulphuric acid (pyrites- and sulphur-based product); Zeolite

(continued)

Product/process	Metals/minerals/rocks used
Ashta Dhatu (8-metal alloy)	Brass, Bronze, Copper, Gold, Iron, Lead, Silver, Tin
Atom bomb	*See* 'fission bomb'
Atomic clock	Cesium, Rubidium
Automotive bodies/ parts	Aluminium, Aluminium foam, Ferrite, Iron powder, Magnesium, Tin, Titanium
Aviation turbine fuel (ATF)	Petroleum including heavy crude oil and oil shale (refinery product, light distillate)
Ayurvedic medicine (traditional Indian system)	Diamond (gem), Gold
Babbitt metal	Antimony (beta form), Copper, Tin
Ballast (railway and ship)	Crushed stone (quartzite etc.)
Balloon	Graphite-based product (grapheme), Lithium hydride (lithium-based product)
Barometer	Mercury
Baseball bat	Rare earth metal—scandium (alloyed with aluminium)
Bearing	Antimony, Cadmium, Graphite, Indium, Lead, Ruby, Sapphire, Silver, White metal
Bearing (nylon)	Molybdenum chemical (sulphide)
Beet sugar	Gypsum, Strontium hydroxide, Zeolite
Bell metal	Copper, Tin
Benzene	Coal, Lignite, Petroleum including heavy crude oil and oil shale (refinery product, aromatic derivative)
Benzole (organic chemical) extraction	Coal, Lignite
Beryllium acetate, bromide, carbonate, fluoride, hydroxide, perchlorate	Beryllium
Beryllium oxide	Beryl
Beverage	Nahcolite, Saltpetre (ordinary or potassium)
	See also 'soda beverage'
Bicycle frame	Rare earth metal—scandium (alloyed with aluminium)
Bio-fertilizer	Lignite, Peat
Bitumen	*See* 'asphalt'
Bleaching (includes bleaching powder)	Aluminium chloride (bauxite-based chemical), Attapulgite/fuller's earth, Slaked lime (lime-based product), Sodium hexa-meta phosphate (phosphoric acid-based product), Rock salt, Sodium dichromate (chromite-based chemical), Sulphur dioxide (pyrites- and sulphur-based product), Sulphuric acid (pyrites- and sulphur-based product)
Board/panel	Aluminium, Asbestos (amosite, chrysotile), Crushed stone (marble dust), Gypsum, Magnesite, Micanite (muscovite-based intermediate product), Muscovite mica (ground/micronized), Vermiculite, Water glass/liquid glass/sodium silicate

(continued)

Product/process	Metals/minerals/rocks used
Boiler/steam pipes (including lagging)	Asbestos (actinolite, anthophyllite, crocidolite), Magnesite, Muscovite mica (block/film/sheet), Perlite (expanded and milled)/ Carlita/Dicalite, Sodium hexa-meta phosphate (phosphoric acid-based product)
Bonding	Bentonite, Cryolite, Petroleum (crude/natural, old usage), Silane (silicon tetra-hydride), Water glass/liquid glass/sodium silicate
Bonding (gold chain elements)	Cadmium
Bonding (tungsten carbide grains)	Cobalt
Bone china	Feldspar, Kaolin (china clay), Phosphorite
Borax (synthetic)	*See* 'synthetic borax'
Boring	*See* 'cutting'
Boro-gypsum	Byproduct from boric acid manufacturing
Boron carbide (ultra-hard material)	Borax-based compound (boric oxide)
Boron nitride/borazon/ wurtzite (ultra-hard material)	Borax-based compound (boric oxide)
Brake/friction material	Asbestos (actinolite, chrysotile, tremolite), Basalt, Diatomite, Graphite, Wollastonite
Brass	Copper, Lead, Zinc
Brass, lead-free	*See* 'EnviroBrass'
Brazing	Indium, Lithium
Brick (common) including surface colouring	Barium chloride, Clay, Coal, Pyrolusite-based chemical (manganese chloride)
Brick (common) and its burning	Brick clay, Brick shale, Coal, Crushed stone (assorted, basalt, diorite, marble dust), Peat, Quartz
Brick (hollow)	Crushed stone (assorted)
Brick (sand-lime)	Building/river sand, Crushed stone (slate powder), Slaked lime (lime-based product)
Britannia metal	Antimony (beta form), Tin
Bitumen	Petroleum
Bronze (*see also* 'porous bronze')	Aluminium, Copper, Graphite, Lead, Lithium, Nickel, Phosphorus (red and yellow), Tin
Bullet/shot/shell	Antimony (beta form), Arsenic, Lead, Tin, Tungsten carbide
Bunsen burner	Coal gas (coal-based product)
Cable sheath	Antimony (beta form), Lead
Calcium carbide	Anthracite, Coal, Lime (or quick lime or fat lime)
Calcium chloride	Limestone, Rock salt
Calico printing	Arsenic-based compound (white arsenic or arsenous oxide), Pyrolusite-based chemical (manganese sulphide), Uranium compounds (salts)
Calomel	Mercury (quick silver)

(continued)

Product/process	Metals/minerals/rocks used
Camera (including filters, lenses, exposure meters)	Rare earth metal (lanthanum), Rare earth metal compound (lanthanum oxide), Selenium, Thallium compound (oxysulphide), Thorium
Candle	Ozokerite/ceresin, Wax/paraffin wax
Canning/packaging	Aluminium, Monel metal, Tin
Capacitor	Aluminium, Muscovite mica (block/film/sheet), Rare earth metal (lanthanum)
Cap-gun caps	Phosphorus (red)
Carbide lamp	*See* 'petromax'
Carbolic acid (organic chemical) extraction	Coal, Lignite
Carbon black/oil black	Natural gas, Petroleum including heavy crude oil and oil shale
Carbon brushes	Graphite
Carbon disulphide	Sulphur
Carbon fibre	Manufactured graphite
Carbon nano-balls	Fullerene (manufactured graphite)
Carbon nano-sheet	Graphene (graphite-based product)
Carbon nano-tube	Fullerene (manufactured graphite)
Carbon sequestration	Peridotite, Serpentite, Zeolite
Carburization	Petroleum gas (including liquefied petroleum gas or LPG)
Casein (soluble milk protein)	Potash group (potassium phosphate)
Cassette (including audio and video)	Chromium dioxide (chromite-based chemical), Ferrite, Hematite, Kaolin (china clay)
Cassette player (including video tape recorder)	Rare earth metal (mischmetall)
Cast iron	Iron/pig iron
Catalyst	Aero-gel/aero-sil/silica aerogel, Alumina, Aluminium chloride (bauxite-based chemical), Aluminium hydroxide (includes activated alumina), Attapulgite/fuller's earth, Cesium, Crushed stone (marble flour), Ferrocene, Gallium compound (halides), Germanium, Kaolin (china clay), Mercury, Molybdenum chemical (oxide), Nickel, Niobium, Platinum (platinum group of metals), Potash group (caustic potash), Potassium, Rare earth metal compounds (cerium oxide, lanthanum oxide, neodymium oxide, praseodymium oxide), Rhenium, Rhenium heptasulphide, Rubidium, Rutile- and anatase-based product (titanium dioxide), Selenium compound, Thorium, Tin-based chemical (stannous chloride), Vanadium-based chemical (vanadium pentoxide), Zeolite
Catalytic converter	Gold (nano-gold), Palladium, Platinum, Rare earth metal (cerium), Rhodium (platinum group of metals)
Cathode ray tube	Alumina (electrically insulating), Potash group (potassium meta-silicate), Rare earth metal (europium, terbium, yttrium), Thorium, Tin-based chemical (stannic oxide)
Caulking	Asbestos (chrysotile)

(continued)

Product/process	Metals/minerals/rocks used
Caustic potash manufacturing	Potash group (potassium chloride)
Caustic soda manufacturing	Limestone, Milk-of-lime (lime-based product), Rock salt
Cell (battery) including alkaline battery, rechargeable cell and dry cell	Antimony (beta form), Cadmium, Calcium, Feldspar, Graphite, Lead, Lithium, Magnesium compound, Mercury compound (mercuric oxide), Nickel, Nickel oxyhydroxide (nickel-based chemical), Potash group (caustic potash), Pyrolusite (gamma type), Silver chloride (silver-based chemical), Sulphuric acid (pyrites- and sulphur-based product), Synthetic manganese dioxide, Zinc
Cement, refractory (calcium aluminate or CAC)	Alumina, Limestone
Cement (including ordinary Portland, high- and low-iron alumina cement, asbestos cement, grouting)	Alum-ammonium (bauxite-based chemical), Aluminium sulphate-ferric (bauxite-based chemical), Asbestos (actinolite, chrysotile, crocidolite, tremolite), Attapulgite/fuller's earth, Bauxite, Boro-gypsum, Building/river sand, Coal, Corundum, Crushed stone (marble flour), Desulpho-gypsum, Dolomite, Fluorite/fluorspar, Fluoro-gypsum, Gypsum, Hematite, Kaolin (china clay), Kimberlite, Limestone, Magnesite, Marine gypsum, Met coke (lignite-based product), Muscovite mica (ground/micronized), Phosphogypsum, Pozzolanic clay, Pyrolusite (beta-type), Water glass/liquid glass/sodium silicate
Cement concrete	Silica fume/silica dust, Fluffy silica/micro-silica (quartz—industrial variety)
Ceramics (including advanced structural ceramics, fired tiles, metal-matrix composites, porcelain, piezoelectric ceramics)	Alumina, Aluminium, Aluminium fluoride (alumina-based chemical), Asbestos (chrysotile), Baddeleyite/zirconia, Ball clay, Barium chromate (chromite-based chemical), Barium hydroxide, Bentonite, Beryllium oxide (a derivative of beryl), Bismuth compounds, Boron, Boron nitride/borazon/wurtzite, Cordierite (artificial), Crushed stone (marble dust and slate powder), Diamond (industrial), Diaspore, Diatomite, Dolomite, Feldspar, Fluorite/ fluorspar, Fluorite-based
	product (aluminium fluoride), Gypsum, Kaolin (china clay), Lithium carbonate (lithium-based product), Magnesium, Molybdenum chemical (disilicide), Nickel oxide (nickel-based chemical), Niobium pentoxide (niobium compound), Perlite (expanded and milled)/Carlita/Dicalite, Petalite (lithium mineral), Pyrolusite (beta-type), Pyrophyllite, Quartz, Rare earth metals (cerium, yttrium), Rare earth metal compound (mixed rare earth metal oxides), Rutile- and anatase-based product (titanium dioxide), Salt cake (sodium sulphate), Selenium compound, Silica sand, Silicon carbide (carborandum), Silicon nitride, Soda ash or soda (sodium carbonate), Sodium aluminate (bauxite-based chemical), Spodumene (lithium mineral), Stoneware clay, Talc, Tellurium, Titanium, Uranium compounds (salts), Wollastonite, Zeolite, Zinc chromate (chromite-based chemical), Zircon/zirconia
Chalk (writing)	*See* 'pencil'
Charcoal briquette	Saltpetre (Chile or nitratine or soda nitre)

(continued)

Product/process	Metals/minerals/rocks used
Chemicals	Anatase, Antimony (beta form), Baddeleyite/zirconia, Barytes, Bauxite, Beryllium, Calcite, Chromite, Cobalt, Copper, Fluorite/fluorspar, Fluorite-based product (fluorine gas), Indium, Lead, Lithium, Molybdenum, Nickel, Phosphorus (red and yellow), Potash group (caustic potash and potassium carbonate), Pyrolusite (beta-type), Rock salt, Rubidium, Rutile, Saltpetre (ordinary or potassium), Sodium, Strontianite, Sulphurous acid (pyrite- and sulphur-based product), Thorium, Tin, Trona, Tungsten, Uranium, Vanadium, Zinc, Zircon
Chemical equipment	Tantalum, Titanium
Chemically activated manganese dioxide	Pyrolusite-based chemical (manganese nitrate)
Chemical reagent (including flotation reagent)	Xylene
Chemical sensor	Synthetic zeolite
Chemical warfare	Arsenic-based compound (lewisite or chloro-vinyl-dichlorarsine)
Chewing (with betel leaves)	Lime (or quick lime or fat lime)
Chlorofluorocarbon (CFC)	Coal, Fluorine-based compound (anhydrous hydrogen fluoride)
Chrome-green	Chromic oxide (chromite-based chemical)
Chrome-plating	Chromic acid (chromite-based chemical), Chromite
Chrome-red	Lead chromate (chromite-based chemical)
Cinema (including photography, projection and screen)	Rare earth metal compound (cerium oxide), Indium
Cleaning	*See* 'purification'
Climatology	Diatomite
Coal dust suppression	*See* 'dust suppression'
Coal gas	Coal
Coal tar	*See* 'asphalt/bitumen/pitch/tar/coal tar
Coal washing/ beneficiation	Barytes, Cobalt-60, Feldspar, Magnetite, Silica sand
Cobalt-60 from cobalt	Uranium-235
Cobalt soap	Cobalt
Coinage	Copper, Nickel, Silver
Coke (coal-based product)	Coal, Coal usage waste (coke breeze)
Collapsible tube	*See* 'tube (collapsible)'
Colloidal graphite	Graphite
Coloured lamp	Rare earth metals (europium, terbium, yttrium)
Communication (including telecommunication)	Copper, Ferrite, Gallium compound (arsenide), Rare earth metals (gadolinium, lanthanum)
Compass	Muscovite mica (block/film/sheet), Osmium (platinum group of metals)

(continued)

Product/process	Metals/minerals/rocks used
Concrete	*See* 'construction'
Condenser (electrical)	Magnesite, Tantalum
Constantan	Copper, Nickel
Construction (including building, concrete, aggregate, floor covering, structural material)	Aero-gel/aero-sil/silica aerogel, Aluminium foam, Barytes, Bentonite, Building/river sand, Crushed stone (assorted, basalt, diorite.), Diamond, Diatomite, Dolomite, Granite sand, Graphite, Gypsum, Hematite, Perlite (expanded and milled)/Carlita/Dicalite, Petroleum (crude/natural, old usage), Rutile- and anatase-based product (titanium dioxide), Shirasu (volcanic eject), Water glass/ liquid glass/sodium silicate, Vermiculite, Zeolite
Container (for radioactive material)	Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38)
Copper sulphate	Copper, Sulphuric acid (pyrite- and sulphur-based chemical)
Cordierite (artificial)	Bauxite, Fireclay, Talc
Cordierite saggars	Cordierite (artificial)
Cosmetics (including antiperspirants, beauty applications, ointments, rouge, talcum powder)	Aluminium carboxylate (bauxite-based chemical), Aluminium chloride (bauxite-based chemical), Bentonite, Bismuth compounds, Borax, Calcite, Gypsum, Hematite, Kaolin (china clay), Magnesite, Mineral jelly/petroleum jelly (petroleum refinery product), Muscovite mica (ground/micronized), Nahcolite, Pyrophyllite, Silica fume/silica dust, Fluffy silica/micro-silica (quartz—industrial variety), Talc, White oil, Zirconium phosphate (baddeleyite- and zircon-based chemicals)
Crayon	*See* 'pencil'
Creosote oil (organic chemical) extraction	Coal, Lignite
Cresols (organic chemical) extraction	Coal, lignite
Crucible	Baddeleyite/zirconia, Fireclay, Graphite, Platinum (platinum group of metals), Silicon carbide (carbo-randum), Thorium compound (oxide or thoria), Zircon/zirconia
Cryogenic fuel	Helium
Cryolite (synthetic)	*See* 'synthetic cryolite'
Cupro-nickel	Copper, Iron, Manganese, Nickel
Currency security (potential use)	Magnesite-based intermediate product (caustic magnesia, ground flakes)
Cutting/boring (including metal cutting)	Cobalt, Diamond (industrial), Hafnium (additive in carbide tools), Nickel, Petroleum gas (including liquefied petroleum gas or LPG), Platinum (platinum group of metals), Silicon carbide (carborandum), Stellite, Tantalum carbide, Titanium, Tungsten carbide, Zirconium
Cymogene	Petroleum (refinery product, light distillate, petroleum ethers)
Damascene art	Copper, Zinc
Davy's lamp (used in underground coal mines)	Coal gas (coal-based product)

(continued)

Product/process	Metals/minerals/rocks used
Decolourizer	Rare earth metal compounds (cerium dioxide, cerium oxide, neodymium carbonate, praseodymium carbonate)
Decoration (various petty consumer items including artifacts, ashtrays, paper weights, pen stands etc. by casting or sculpting)	Calcite (dogtooth spar and Mexican onyx), Crushed stone (agglomerated stone), Dimension stones (commercial granite, commercial limestone, commercial marble, commercial sandstone), German silver, Gypsum, Gypsum (alabaster), Muscovite mica (ground/micronized), Pyrophyllite, Silver, Talc, Terracotta clay, Terracotta shale, Tin, Tourmaline
Degasification	Barium, Calcium, Ferro-boron, Lithium, Magnesium, Rutile- and anatase-based chemical (titanium tetrachloride), Silica gel, Strontium and its alloys, Tantalum, White oil, Zirconium
De-icing	Calcium, Magnesium acetate, Crushed stone (marble flour), Magnesite, Rock salt
Deliquescent	Magnesium compound, Saltpetre (lime)
Denaturing agent (alcohol, nuclear fuel etc.)	Methanol (methane-based product)
Dentistry	Baddeleyite/zirconia, Copper, Feldspar, Gold, Indium, Iridium (platinum group of metals), Mercury, Palladium and Platinum (platinum group of metals), Rare earth metals (lanthanum, samarium, yttrium), Silver, Tantalum, Tin, Zircon/zirconia
Deoxidizer	Barium, Coal tar, Coke (coal-based product), Ferro-boron, Ferrosilicon, Lignite, Magnesium, Manganese, Natural gas, Phosphorus; Psilomelane, Rare earth metal (mischmetall), Silicomanganese, Thorium, Zirconium
Desiccation (including oil drying)	Aero-gel/aero-sil/silica aerogel, Aluminium hydroxide (includes activated alumina), Bauxite, Cobalt soaps, Lead compounds (acetate, hydroxide of lead and lead soap), Lithium bromide (lithium-based product), Lithium chloride (lithium-based product), Peat, Potash group (potassium carbonate), Pyrolusite-based chemicals (manganese borate, manganese linoleate, manganese naphthenate, manganese oxalate, manganese resinate), Quartz, Silica gel, Zinc-based chemical (zinc sulphate)
De-staining	Alum-ammonium (bauxite-based chemical), Aluminium sulphate—iron-free (aluminium hydroxide-based chemical), Rutile- and anatase-based chemicals (titanous chloride and sulphate)
Desulphurization	Barium peroxide, Celestite, Limestone, Manganese, Rhodochrosite, Psilomelane, Rare earth metal (mischmetall), Silicomanganese, Zirconium
Detergent	*See* 'soap'
Detonator	Barium nitrate, Mercury compound (mercury cyanate)
Diamond (artificial/synthetic)	*See* 'artificial/synthetic diamond'
Diamond dressing	Boron carbide, Ferrosilicon, Rhenium diboride
Die (for ceramic tools)	Boron carbide
Die (for wire drawing)	Diamond (industrial), Indium, Tantalum carbide, Tungsten carbide
Die casting	Aluminium, Magnesium (alloys), Zinc

(continued)

Product/process	Metals/minerals/rocks used
Diesel (high speed or HSD)	Petroleum including heavy crude oil and oil shale (refinery product, middle distillate), Saltpetre (lime)
Diesel generator (starting fuel)	Producer gas (coal-based product)
Diesel oil (light or LDO)	Petroleum including heavy crude oil and oil shale (refinery product, middle distillate)
Diet coke	Magnesite
Disinfectant/fumigant	Naphthalene (petroleum derivative, slightly unsaturated), Pyrolusite-based chemical (potassium permanganate), Rock salt, White oil
Distance, measurement of	Calcite (Iceland spar)
Domestic heating (including cooking)	Anthracite, Coal, Kerosene (petroleum refinery product, middle distillate), Leco (lignite-based pro-duct), Lignite, Methane (abandoned and working mine, coal bed and coal mine ventilation air methane), Natural gas, Zirconium (heating apparatus), Petroleum gas (petroleum refinery product, light distillate)
Dosimeter	*See* 'thermal dosimeter'
Drilling (including proppant)	Aluminium carboxylate (bauxite-based chemical), Attapulgite/fuller's earth, Barytes, Bauxite, Bentonite, Causticized lignite/sodium lignite, Celestite, Cobalt, Graphite, Hematite, Muscovite mica (ground/micronized), Nickel, Perlite (expanded granules), Silica sand (frac sand or hydraulic fracturing sand), Sodium dichromate (chromite-based chemical), Tungsten carbide, Vermiculite
Dry cleaning	White spirit
Dust suppression (including coal dust)	Gypsum, Magnesite
Dye/dyeing/dyestuff	*See* 'paint (pigment and dye)'
Dynamite	*See* 'explosion'
Ebonite	Sulphur
Edible fat	Wax/paraffin wax
Edible salt (includes iodized salt and free-flowing table salt)	Borax, Calcium silicate, Magnesite (old use), Rock salt
Electrical appliances	Copper, Magnesite, Molybdenum chemical (sulphide), Muscovite mica (block/film/sheet), Phlogopite mica, Rare earth metal(lanthanum), Tungsten, Vanadium-based chemicals (ammonium vanadate, vanadium pentoxide)
Electrical transmission	Aluminium, Copper, Metallic glass (special type of ferro-boron), Silvered mica (muscovite-based intermediate product)
Electric arc furnace (EAF)	Calcium chloride
Electric bulb	Molybdenum, Rhenium, Thorium, Thorium compound (oxide or thoria), Tungsten
Electric cable	Cadmium, Silicone (elastomer/silicon rubber), Talc

(continued)

Product/process	Metals/minerals/rocks used
Electric equipment (motor/generator/ transformer, portable transformer, switch-gear)	Alumina (electrically insulating), Copper, Ferrite, Ferrosilicon, Iron powder, Lubricating oil (petroleum refinery product, heavy end), Metallic glass (special type of ferro-boron), Micanite (muscovite-based intermediate product), Monel metal, Muscovite mica (block/ film/sheet), Palladium and platinum (platinum group of metals), Porous bronze (graphite-based product), Silicone (resins), Tin-based chemical (organo-tin compounds), Tungsten
Electro-ceramics	Baddeleyite/zirconia, Talc, Zircon/zirconia
Electrochemical boring	ALON (aluminium oxy-nitride)
Electrode	Calcite, Petroleum coke (petroleum refinery product, heavy end), Synthetic graphite (manufactured graphite), Thorium, Wollastonite
Electrode boring	Platinum (platinum group of metals)
Electrolytic manganese dioxide (EMD)	Pyrolusite
Electronic equipment (includes computer)	Alumina (electrically insulating), Aluminium, Barium, Copper, Diamond (gem), Diamond (nano), Ferrite, Gallium, Germanium, Graphite-based product (grapheme), Molybdenum, Muscovite mica (block/film/sheet), Nickel, Nickel-coated mica (muscovite-based intermediate product), Quartz, Rare earth metals
	(europium, lanthanum, terbium, yttrium), Silicon, Silicone (elastomer/silicon rubber), Silver, Strontium and its alloys, Tantalum, Tin-based chemical (indium tin oxide, potassium stannate)
Electro-optical modulator	Lithium niobate (lithium-based product)
Electroplating/metal plating	Borax, Cadmium, Fluorite-based product (fluoro-boric acid and fluoro-silicic acid), Indium, Magnesium, Nickel, Nickel sulphate (nickel-based chemical), Palladium (platinum group of metals), Potash group (caustic potash and potassium carbonate), Pyrolusite, Rhenium, Silver, Tin
Emery (artificial)	Bauxite, Corundum, Magnetite
EMI-shield	Colloidal graphite (graphite-based product), Nickel-coated mica (muscovite-based intermediate product)
Emulsifier	Bentonite
Enamel	Aluminium fluoride (alumina-based chemical), Antimony-based chemical (antimony oxide), Baddeleyite/zirconia, Borax, Cadmium sulphide or cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Cryolite, Feldspar, Fluorite/fluorspar, Fluorite-based product (aluminium fluoride), Magnesite, Potash group (potassium carbonate), Pyrolusite (beta-type), Quartz,
	Rutile- and anatase-based product (titanium dioxide), Saltpetre (Chile or nitratine or soda nitre), Sulphuric acid (pyrites- and sulphur-based product), Tin-based chemical (stannic oxide), Zircon/ zirconia
Engineering construction (beams, bridges, pavements etc.)	Dimension stones (commercial granite)

(continued)

Product/process	Metals/minerals/rocks used
EnviroBrass (lead-free brass)	Bismuth, Copper, Selenium, Zinc
Epoxy	Aluminium powder
Epsom salt	Magnesite
Etching (glass, semiconductor)	Fluorine-based compound (fluoro-carbon), Fluorite-based product (hydrofluoric acid), Potassium di-chromate (chromite-based chemical)
Ethylene	Petroleum including heavy crude oil and oil shale
Expanded/exfoliated graphite	Graphite
Expanded perlite	Perlite
Explosion/explosive/ pyrotechnics (including gun powder, dynamite)	Aluminium powder, Attapulgite/fuller's earth, Barytes, Diatomite, Graphite, Kaolin (china clay), Potassium dichromate (chromite-based chemical), Mineral jelly/petroleum jelly (petroleum refinery product), Rock salt, Saltpetre (Chile or nitratine or soda nitre), Saltpetre (lime), Saltpetre (ordinary or potassium), Sulphur, Talc, Toluene (petroleum derivative, slightly unsaturated aromatic), Zirconium
Fax machine	Selenium
Ferrite	Barium, Hematite, Nickel oxide (nickel-based chemical), Pyrolusite, Strontium, Zinc-based chemical (zinc oxide)
Ferro-boron	Boric acid, Boric oxide
Ferrocene (organic compound of iron)	Hematite
Ferro-chrome (charge chrome, exothermic ferrochrome, high-carbon, low-carbon, medium-carbon, silico-chrome)	Coke (coal-based product), Chromite
Ferro-manganese	Coke (coal-based product), Dolomite, Limestone, Psilomelane
Ferromolybdenum	Fluorite/fluorspar, Molybdenum
Ferrosilicon	Iron, Quartz
Ferrovanadium	Vanadium-based chemical (vanadium pentoxide)
Fertigation (fertilizer and irrigation combined)	Saltpetre (ordinary or potassium)
Fertilizer	Aluminium hydroxide (includes activated alumina), Ammonia, Anhydrite, Cobalt, Crushed stone (marble flour), Diatomite, Dolomite, Fluoro-gypsum, Gypsum, Limestone, Methane, Naphtha (petroleum refinery product, light distillate), Phosphogypsum, Phosphorite, Potash group (potassium chloride, phosphate, schoenite and sulphate), Quartz, Saltpetre (Chile or nitratine or soda nitre), Saltpetre (lime), Saltpetre (ordinary or potassium), Shirasu (volcanic eject), Sulphuric acid (pyrites- and sulphur-based product), Tourmaline, Vermiculite, Zeolite, Zinc sulphate
Fertilizer carrier	Crushed stone (slate powder), Perlite (expanded and milled)/Carlita/ Dicalite

(continued)

Product/process	Metals/minerals/rocks used
Fertilizer (plant micronutrient)	*See* 'plant nutrients and their measurement'
Fibre glass (manufacturing machinery)	Gold, Platinum and rhodium (platinum group of metals)
Film-processing	Potassium dichromate (chromite-based chemical)
Filter/filtration	Asbestos (actinolite, anthophyllite, chrysotile), Building/river sand, Diatomite, Dolomite, Fluorine-based compound (fluoro-carbon), Magnesite, Perlite (expanded and milled)/Carlita/Dicalite
Fire alarm	Gallium
Fire extinguishing	Alum-ammonium (bauxite-based chemical), Aluminium sulphate-ferric (bauxite-based chemical), Antimony-based chemicals (antimony chloride), Potash group (potassium carbonate)
Fire proofing	*See* insulator (heat)
Fire retardant	Borax, Tin-based chemical (zinc hydroxyl stannate and stannate)
Fishery	Zeolite
Fission bomb/atom bomb	Plutonium-239, Uranium-235
Floriculture	Zeolite
Fluorescent light applications (sign board, screen etc.) including surface coating substance	Calcium tungstate, Indium compounds (oxide, sulphide), Magnesium tungstate, Phosphor, Phosphorus (yellow), Rare earth metal (dysprosium), Tin-based chemical (stannic oxide), Zinc-based chemical (zinc sulphido-silicate), Zinc-beryllium silicate (beryllium-based chemical)
Fluorine gas	Fluorite-based product (hydrofluoric acid and potassium fluoride)
Fluoro-gypsum	Byproduct from hydrofluoric acid manufacturing
Fluoro-silicic acid	Fluorite-based product (hydrofluoric acid)
Foil (for wrapping food etc.)	Aluminium, Tin
Food can	*See* 'canning/packaging'
Food processing	Borax, Phosphoric acid-based products (di-sodium phosphate, sodium mono-phosphate, sodium pyro-phosphate, sodium tri-poly-phosphate, tetra-sodium phosphate, tri-sodium phosphate), Potash group (potassium carbonate), Rock salt
Forsterite	Magnesite, Talc
Foundry (metal casting)	Aluminium fluoride (alumina-based chemical), Bauxite, Bentonite, Chromite, Coal, Corundum,
	Ferrosilicon, Foundry/moulding sand, Graphite, Gypsum, Iron, Magnesium (alloys), Muscovite mica (ground/micronized), Perlite (expanded and milled)/Carlita/Dicalite, Perlite (natural), Synthetic graphite (manufactured graphite), Zinc, Zircon
Fountain pen nib	Osmium (platinum group of metals), Rhenium, Tantalum, Zirconium
Friction material	*See* 'brake'
Fruit ripening	Calcium carbide

(continued)

Product/process	Metals/minerals/rocks used
Fuel cell	Baddeleyite/zirconia, Graphite, Methanol, Natural gas, Petroleum, Phosphoric acid, Rare earth metal (terbium), Rare earth metal compound (cerium oxide or ceria), Zircon/zirconia
Fullerene	Graphite (manufactured)
Fungicide	*See* 'insecticide'
Furnace/oven	Barium peroxide, Muscovite mica (block/film/sheet), Platinum (platinum group of metals)
Furnace fuel oil	Petroleum including heavy crude oil and oil shale (refinery product, heavy non-fuel end)
Furniture (shelves, stools, table frames, table tops)	Dimension stones (commercial granite, commercial limestone, commercial marble, commercial sandstone, commercial slate)
Fused quartz	Lasca
Fuse wire	*See* 'safety fuse'
Fusion power generation	*See* 'thermonuclear reactor'
Galvanizing	Sulphuric acid (pyrites- and sulphur-based product), Zinc
Garnet (synthetic)	Rare earth metals (gadolinium, ytterbium)
Gasket	*See* 'packing'
Gas mantle	Rare earth metal compound (cerium oxide), Thorium compound (nitrate, oxide or thoria)
Gasoline	*See* 'motor fuel or Mo-gas (petroleum (refinery) product, light distillate)'
Gear	Sintered graphite (graphite-based product)
Geiger counter	Muscovite mica (block/film/sheet)
Gem (*See also* 'ornament')	Amber, Andalusite, Apatite, Apophyllite, Aqua marine, Axinite, Bixbite, Bowenite, Chrysoberyl (alexandrite and cat's eye), Coral, Danburite, Diamond (gem), Diopside, Emerald, Enstatite, Epidote, Euclase, Feldspar (amazonite, moonstone, sunstone), Fluorite/
	fluorspar, Fuchsite quartzite/Greenlandite/Indian jade, Garnet, Hambergite, Idiocrase, Iolite (cordierite), Jadeite/jade, Kyanite, Lazurite (lapis lazuli), Malachite, Morganite (vorobyevite), Nephrite, Opal, Pearl, Phenacite, Piedmontite, Prehnite, Pyrites—marcasite (trade name, not true marcasite), Quartz (agate, amethyst, aventurine, blood stone, chalcedony, citrine, onyx, plasma, rock crystal/crystal quartz, rose quartz, smoky quartz, star stone/star quartz, tiger-eye), Rhodonite, Ruby, Rutile, Sapphire, Scapolite, Sillimanite, Sodalite, Sphene, Spinel (blue and red), Staurolite, Topaz, Tourmaline (achroite, Brazilian sapphire, indicolite, rubellite, schorl, verdelite), Turquoise, Zeolite (thomsonite), Zircon (hyacynth, jargon, starlite), Zoisite
Gem (artificial)	*See* 'synthetic gem'
Gem (synthetic)	*See* 'synthetic gem'

(continued)

Product/process	Metals/minerals/rocks used
Gemmotherapy	Amber, Andalusite, Apatite, Aqua marine, Chrysoberyl (alexandrite and cat's eye), Coral, Corundum, Diamond (gem), Emerald, Feldspar, Fluorite/fluorspar, Fuchsite quartzite/Greenlandite/Indian jade, Garnet, Iolite (cordierite), Jadeite/jade, Kyanite, Llazurite (lapis lazuli), Malachite, Nephrite, Pearl, Pyrites, Quartz, Ruby, Rutile, Sapphire, Sillimanite, Spinel (blue and red), Staurolite, Topaz, Tourmaline (achroite, Brazilian sapphire, indicolite, rubellite, schorl, verdelite), Turquoise, Zircon, Zoisite
Geological dating	Baddeleyite, Rubidium-87, Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38), Zircon
German silver	Copper, Nickel, Zinc
Germicide/disinfectant	*See* 'insecticide'
Glass (including coloured glass, optical glass, optical fibre, photochromatic glass, float glass, special glass)	Aluminium fluoride (alumina-based chemical), Arsenic-based compound (white arsenic or arsenous oxide), Baddeleyite/zirconia, Barium, Barium carbonate, Barium oxide, Barytes, Bismuth compounds, Borax/colemanite/ulexite, Cadmium sulphide or Cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Calcite, Chromic oxide (chromite-based chemical), Cryolite, Dolomite, Feldspar, Fluorite/fluorspar, Fluorine-based compound (sodium fluoro-silicate/hexa-fluro-silicate/silico-fluoride), Fluorite-based product (aluminium fluoride), Indium compound (sesquioxide), Kaolin (china clay),
	Kyanite, Lead, Lead compounds (oxides—PbO, PbO_2 and Pb_3O_4), Lepidolite (lithium mineral), Lithium, Limestone, Magnesite, Nickel arsenide (nickel-based chemical), Niccolite, Niobium pentoxide (niobium compound), Petalite (lithium mineral), Phosphorite, Platinum (platinum group of metals), Potash group (potassium carbonate), Potassium, Pyrolusite (beta-type), Pyrophyllite, Rare earth metal (cerium, neodymium, praseodymium, yttrium), Rare earth metal compounds (cerium dioxide, cerium oxide, neodymium carbonate, praseodymium carbonate), Rutile- and anatase-based chemicals (titanous chloride and sulphate), Saltpetre (Chile or nitratine or soda nitre), Saltpetre (ordinary or potassium), Selenium, Selenium compound, Silica sand, Sodium, Sodium aluminate (bauxite-based chemical), Sodium dichromate (chromite-based chemical), Spodumene (lithium mineral), Strontium carbonate, Tellurium, Thallium, Thallium compound (oxides), Thorium, Tin, Tin-based chemical (stannic oxide), Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38), Uranium compounds (salts), Vanadium-based chemicals (ammonium vanadate, vanadium dioxide, vanadium pentoxide), Vermiculite, Zeolite, Zircon/zirconia. (*See also* 'optical fibre')
Glass-bonded mica	Muscovite mica (scrap)
Glass, metallic	*See* 'metallic glass'
Glass (perfect glass)	Zeolite
Glass wool	*See* 'mineral wool'
Glassy steel	Hematite

(continued)

Product/process	Metals/minerals/rocks used
Glazing	Baddeleyite/zirconia, Ball clay, Barium oxide, Borax, Calcite, Chromic oxide (chromite-based chemical), Diatomite, Feldspar, Kaolin (china clay), Lead compounds (oxides—PbO, PbO_2 and Pb_3O_4 and molybdate), Limestone, Magnesite, Nepheline syenite, Petalite (lithium mineral), Phosphorite, Quartz, Rare earth metal compound (mixed rare earth metal oxides), Rock salt, Rutile- and anatase-based product (titanium dioxide), Spodumene (lithium mineral), Uranium compounds (salts), Vanadium-based chemicals (ammonium vanadate, vanadium pentoxide), Zircon
Global positioning system (GPS)	Rubidium
Goggles (including those used by glass-blowers)	Rare earth metal compounds (cerium oxide, neodymium oxide, praseodymium oxide)
Gold fabrication	Iridium and ruthenium (platinum group of metals)
Gramophone record	Crushed stone (slate powder)
Graphene	Graphite
Graphite/carbon fibre	Graphite (manufactured)
Graphite purification	Fluorine-based compound (chlorofluorocarbon)
Grease	*See* ‘lubricant’
Grinding	Alumina, Quartz (flint pebbles), (*see also* ‘abrasive’)
Grip strengthener	Silicone (silli-putty)
Gun metal (admiralty bronze)	Copper, Tin, Zinc
Gun powder	*See* ‘explosion’
Hair dye	Benzene
Hair oil	White oil
Hair remover	Orpiment (arsenic trisulphide)
Halogen/quartz bulb	Quartz
Handling/storage (including cryogenic chemicals)	Aluminium, Diatomite, Perlite (expanded and milled)/Carlita/Dicalite
Head phone	Rare earth metal (mischmetall)
Hearing aid	Germanium
Heating	Zeolite
Heating, domestic	*See* ‘domestic heating’
Heating, industrial	*See* ‘industrial heating’
Heat sink	Diamond (industrial)
Heavy fuel oil	Petroleum including heavy crude oil and oil shale (refinery product, heavy end)
Heavy water	Potassium
Helium recovery	Natural gas
Herbicide (including glysophate)	Borax-based chemicals (boric acid, sodium borate and sodium perborate), Potash group (caustic potash), Perlite (expanded and milled)/Carlita/Dicalite, Phosphorus (yellow)
Horn (electric)	Tungsten

(continued)

Product/process	Metals/minerals/rocks used
Horticulture	*See* 'agriculture'
Hydraulic brake	Borax-based chemical (sodium organo-borate or liquibor)
Hydraulic/natural cement	Limestone
Hydrofluoric acid	Fluorite/fluorspar
Hydrogenation	Nickel, Palladium (platinum group of metals), Rhenium, Rhenium heptasulphide, Rubidium, Siderite (after calcination)
Hydrogen bomb	*See* 'thermonuclear reactor'
Hydrogen fuel system	Magnesium
Hydrogen peroxide	Barium peroxide
Hydrogen production	Rutile- and anatase-based product (titanium dioxide), Strontium titanate (both in experimental stage)
Hydrogen sulphide	Asbestos (chrysotile), Sulphur
Hydroponics	Basalt, Diatomite, Perlite (expanded and milled)/Carlita/Dicalite, Vermiculite, Zeolite
Hydroquinone (quinol benzene)	Pyrolusite
Ice-cream	Saltpetre (ordinary or potassium)
Ice-box	Perlite (expanded and milled)/Carlita/Dicalite
Ice manufacturing	Cymogene (petroleum ether, refinery product, light distillate)
Imitation marble	*See* 'synthetic marble'
Incandescent light	Radium, Rare earth metal compound (cerium oxide)
Incandescent mantle	Monazite, Saltpetre (lime)
Industrial furnace (initial heating)	Producer gas (coal-based product)
Industrial heating (as fuel and for initial firing of furnace, engine etc.)	Anthracite, Coal, Lignite, Methane (abandoned and working mine, coal bed and coal mine ventilation air methane), Furnace fuel oil (petroleum refinery product, heavy end), Met coke (lignite-based product), Natural gas
Industrial machinery fuel (tractors, concrete mixer etc.)	Light diesel oil or LDO (petroleum refinery product, middle distillate)
Infrared optics	Germanium, Indium compounds (oxide, sulphide), Rare earth metal (samarium), Thallium compound (bromo-iodide)
Inhibitor	Sodium chromate hydrated (chromite-based chemical)
Injection syringe	Silicone (oils)
Ink (including indelible ink)	Borax, Kaolin (china clay)
Ink (printing)	Alum-ammonium (bauxite-based chemical), Aluminium sulphate-ferric (bauxite-based chemical), Cadmium sulphide or cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Carbon black, Mercury compound (mercury sulphide), Potassium dichromate (chromite-based chemical), Vanadium-based chemicals (ammonium vanadate, vanadium pentoxide)

(continued)

Product/process	Metals/minerals/rocks used
Insecticide/pesticide/ germicide/fungicide (including carrier)	Aero-gel/aero-sil/silica aerogel, Arsenic-based com-pound (white arsenic or arsenous oxide), Attapulgite/fuller's earth, Bentonite, Borax-based chemical (boric acid, sodium borate and sodium perborate), Crushed stone (slate powder), Cryolite, Diaspore, Diatomite, Flower-of-sulphur (sulphur-based product), Gypsum, Kaolin (china clay), Lead compound (arsenate), Limestone, Mercury compound (mercuric chloride), Muscovite mica (ground/ micronized), Perlite (expanded and milled)/Carlita/Dicalite, Pyrites (Copperas/Melanterite), Pyrolusite-based chemical (manganese ethylene-bisdithio-carbonate, potassium permanganate), Pyrophyllite, Quartz, Selenium compound, Talc, Thallium compound (carbonate), Vermiculite
Insulation brick	Muscovite mica (ground/micronized)
Insulator (electrical)	Alumina (electrically insulating), Asbestos (chrysotile), Asphalt/ bitumen/pitch/tar, Crushed stone (slate powder), Glass-bonded mica/micalex (muscovite-based intermediate product), Kaolin (china clay), Magnesite, Muscovite mica (block/film/sheet), Silicone (resins), Talc, Wax/paraffin wax, Zeolite, Zirconia/zirconium
Insulator (heat)/fire proofing	Aero-gel/aero-sil/silica aerogel, Antimony compounds, Asbestos (actinolite, tremolite), Basalt, Borax, Diatomite, Ferrocene, Muscovite mica, Perlite (expanded and milled)/Carlita/Dicalite, Shirasu (volcanic eject), Sodium tungstate, Vermiculite, Water glass/ liquid glass/sodium silicate
Insulator (high temperature)	Asbestos (amosite)
Insulator (magnetic)	Muscovite mica
Insulator (sound)	Asbestos, Basalt, Crushed stone (slate powder), Diatomite, Gypsum, Perlite (expanded and milled)/Carlita/Dicalite, Vermiculite
Iron nugget (nodule)	Bentonite, Coal, Magnetite
Iron/pig iron	Coke (coal-based product), Dolomite, Hematite, Limestone, Natural gas
Iron powder manufacturing	Iron, Iron carbonyl
Isostatic graphite mould	Graphite
Jar caps	Zinc
Jet engine	Rhenium, Tantalum
Jet (fighter)	Rare earth metal (scandium)
Jewellery	*See* 'ornament'
Jointing sheet	Asbestos (chrysotile)
Kanthal (iron-chromium alloy)	Chromite
Keene's plaster	Gypsum
Kerosene	Petroleum including heavy crude oil and oil shale (refinery product, middle distillate)
Lacquer—filler	Zirconia

(continued)

Product/process	Metals/minerals/rocks used
Lamp (household)	Kerosene (petroleum refinery product, middle distillate), Petroleum (crude/natural, old usage), Phosphorite
Lamp, incandescent/arc	Rare earth metal compound (cerium compound)
Laser/maser	Aluminium, Diamond (gem, industrial and artificial/synthetic), Fused quartz, Garnet, Graphite, Indium compounds (antimonide, arsenide, phosphide), Muscovite mica (block/film/sheet), Rare earth metals (europium, neodymium, terbium, thulium, yttrium), Ruby, Sapphire
LCD display	Gallium phosphoride
Lead soap	Lead
Leather (includes de-staining agent, filler)	Alum-ammonium (bauxite-based chemical), Aluminium sulphate—iron-free (aluminium hydroxide-based chemical), Barium chloride, Cadmium sulphide or cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Chromium sulphate (basic chromite-based chemical), Dolomite, Potash-chrome alum (chromite-based chemical), Pyrolusite-based chemical (manganese sulphide), Rutile- and anatase-based chemicals (titanous chloride and sulphate), Selenium compound, Slaked lime (lime-based product), Sodium dichromate (chromite-based chemical), Uranium compounds (salts), Zirconia
Lenses	Germanium, Lead glass, Rare earth metal compounds (cerium oxide, lanthanum oxide, neodymium oxide, praseodymium oxide), Tantalum oxide, Rhorium
Lighter (gas, cigarette)	Rare earth metals (cerium, mischmetall), Rock crystal (quartz—gem variety)
Lime (or quick lime or fat lime) manufacturing	Dolomite, Limestone
Lime (or quick lime or fat lime) burning	Anthracite, Coal, Peat
Limelight	Lime (or quick lime or fat lime), Zirconium
Lime (or quick lime or fat lime) wool	*See* ‘mineral wool’
Lining	*See* ‘sealing’
Linoleum cloth	*See* ‘vinyl sheet’
Lipowitz’s metal	Bismuth, lead, tin
Liquefied natural gas (LNG)	Natural gas
Liquefied petroleum gas (LPG)	Natural gas, Petroleum (refinery product, light distillate)
Liquid glass	*See* ‘water glass’
Liquid-mirror telescope (for use on moon surface)	Silver
Lithography	Potassium dichromate (chromite-based chemical)
Locomotive	Coal
Loud speaker	Ferrite, Iron powder, Rock crystal (quartz—gem variety)

(continued)

Product/process	Metals/minerals/rocks used
Lubricant/grease	Aluminium carboxylate (bauxite-based chemical), Aluminium-mica alloy (muscovite-based intermediate product), Asphalt/bitumen/pitch/tar, Barium hydroxide, Crushed stone (slate powder), Graphite, Lithium stearate or metallic soap (lithium-based product), Lubricating oil (petroleum derivative, slightly unsaturated aromatic), Molybdenum chemical (sulphide), Muscovite mica (ground/micronized), Petroleum (refinery product, heavy non-fuel end), Potash group (caustic potash), Silicone (oils), Talc, Tin-based chemical (organo-tin compounds), Tungsten sulphide (tungsten-based chemical), Vermiculite, Wax/paraffin wax
Lubricating oil	Petroleum including heavy crude oil and oil shale (refinery product, heavy non-fuel end)
Magnet (including low-temperature and permanent magnet)	Alnico, Aluminium powder, Boron, Cobalt, Ferrite, Iron, Iron powder, Rare earth metals (cerium, erbium, neodymium, praseodymium, samarium), Titanium, Zirconium
Magnetic field measurement	Germanium
Magnetic shield	Mu-metal or permalloy
Magnetic tape	Graphite
Magneto	Palladium and platinum (platinum group of metals)
Malaria control	Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38)
Manganese borate	Pyrolusite
Manganese carbonate	Pyrolusite
Manganese chloride	Pyrolusite
Manganese dioxide (synthetic)	*See* 'electrolytic manganese dioxide and chemically activated manganese dioxide'
Manganese ethylene-bisdithio-carbonate	Pyrolusite
Manganese linoleate	Pyrolusite
Manganese monoxide	Pyrolusite
Manganese naphthenate	Pyrolusite
Manganese nitrate	Pyrolusite
Manganese oxalate	Pyrolusite
Manganese phosphate	Pyrolusite
Manganese resinate	Pyrolusite
Manganese sulphate	Pyrolusite
Manganese sulphide	Pyrolusite
Manganin	Copper, Manganese, Nickel
Manometer (instrument for measuring high pressure and fluid compressibility)	Tourmaline
Marble (imitation)	*See* 'synthetic marble'

(continued)

Product/process	Metals/minerals/rocks used
Marine gypsum	Byproduct from recovery of common salt from seawater
Marine engine	Rare earth metal (gadolinium)
Marinel (Multi-metal alloy)	Aluminium, Chromium, Copper, Iron, Manganese, Nickel, Niobium
Maser	*See* 'laser'
Matches (including sticks)	Antimony-based chemical (antimony oxide), Diatomite, Kaolin (china clay), Phosphorus, Potassium dichromate (chromite-based chemical), Saltpetre (lime), Pyrolusite-based chemical (manganese sulphide), Saltpetre (ordinary or potassium), Sulphur, Wax/paraffin wax
Medical application	Antimony-based chemical (tartar emetic), Arsenic-based compounds (calcium and lead arsenates), Borax-based chemical (boric acid), Diatomite, Mercury compound (mercuric chloride), Rare earth metals (europium, holmium, yttrium), Silver
Mercury lamp	Mercury, Rare earth metal (dysprosium), Rubidium, Thorium
Mercury switch	Mercury, Molybdenum
Mercury vapour boiler (for power generation)	Mercury
Mercury vapour lamp	*See* 'mercury lamp'
Met-coke	Lignite
Metakaolin (china clay)	Kaolin (china clay)
Metallic glass	Borax-based chemicals (boric acid, boric oxide)
Metallic soap	*See* 'lithium stearate (lithium compound)'
Metallization/metal powder	Chromium, Iron, Magnesium, Manganese, Molybdenum, Tin, Tungsten
Metal plating	*See* 'electroplating'
Metallurgy including alloys and process—Aluminium	Alumina, Aluminium fluoride (alumina-based chemical), Bauxite, Cryolite, Fluorite-based product (aluminium fluoride), Fluorite-based product (potassium fluoride)
Metallurgy including alloys and process—Antimony	Stibnite
Metallurgy including alloys and process—Arsenic	Arsenopyrite
Metallurgy including alloys and process—Barium	Barium chloride, Barytes
Metallurgy including alloys and process—Beryllium	Beryllium oxide (a derivative of beryl), Calcite, Lead compound (PbO_2)
Metallurgy including alloys and process—Bismuth	Bismite (bismuth ochre)
Metallurgy including alloys and process—Boron	Borax-based chemicals (boric acid, boric oxide), Magnesium

(continued)

Product/process	Metals/minerals/rocks used
Metallurgy including alloys and process—Calcium	Limestone (through calcium chloride route)
Metallurgy including alloys and process—Chromium	Chromic oxide (chromite-based chemical), Chromite, Coke (coal-based product)
Metallurgy including alloys and process—Copper	Barium, Borax, Bornite, Chalcocite, Chalcopyrite, Coke (coal-based product), Lithium, Rare earth metal (mischmetall), Selenium, Sulphuric acid (pyrites- and sulphur-based product), Tellurium, Waste product associated with zinc recovery process (copper cake)
Metallurgy including alloys and process—Gold	Copper, Germanium, Mercury, Zinc
Metallurgy including alloys and process—Iron/pig iron	Anthracite, Bauxite, Bentonite, Bog iron ore, Boron carbide, Coal, Coal tar, Coke (coal-based product), Dolomite, Dunite, Ferro-boron, Ferrosilicon, Fluorite/fluorspar, Goethite (minette), Hematite, Limestone, Limonite (brown iron ore), Magnetite, Met coke (lignite-based product), Natural gas, Pellets, Psilomelane, Pyroxenite, Quartzite, Rare earth metal (mischmetall), Rhodochrosite, Serpentinite, Siderite (after calcination), Sinters, Taconite, Thorium
Metallurgy including alloys and process—Lead	Borax, Coal, Coke (coal-based product), Galena, Sulphuric acid (pyrites- and sulphur-based product)
Metallurgy including alloys and process—Lithium	Amblygonite, Lepidolite, Petalite, Spodumene
Metallurgy including alloys and process—Magnesium	Calcium chloride (limestone-based product), Dolomite, Magnesite, Pyrolusite-based chemical (manganese chloride), Silicon, Sulphur
Metallurgy including alloys and process—Manganese	Dolomite, Psilomelane, Pyrolusite-based chemical (manganese sulphate), Silicon
Metallurgy including alloys and process—Mercury (quick silver)	Cinnabar
Metallurgy including alloys and process—Mesothorium	Monazite
Metallurgy including alloys and process—Molybdenum	Aluminium powder, Fluorite/fluorspar, Hematite, Molybdenite, Thorium
Metallurgy including alloys and process—Nickel	Coke (coal-based product), Garnierite, Gypsum, Pentlandite
Metallurgy including alloys and process—Niobium	Columbite, Fluorite-based product (hydrofluoric acid), Fluorite-based product (potassium fluoride), Pyrochlore, Tantalite

(continued)

Product/process	Metals/minerals/rocks used
Metallurgy including alloys and process—Potassium	Calcium carbide (lime-based product), Potash group (potassium fluoride, a fluorite-based chemical)
Metallurgy including alloys and process—Rare earth metal	Bastnasite, Gadolinite, Monazite, Xenotime
Metallurgy including alloys and process—Rhenium	Molybdenite
Metallurgy including alloys and process—Rubidium	Lepidolite
Metallurgy including alloys and process—Silver	Argentite, Cerargyrite, Mercury, Zinc
Metallurgy including alloys and process—Sodium	Rock salt
Metallurgy including alloys and process—Steel	Bauxite, Celestite, Coke (coal-based product), Dolomite, Feldspar, Ferrochrome (including charge chrome and high-, medium- and low-carbon ferrochrome, silico-chrome), Ferromanganese, Ferrosilicon, Ferrovanadium, Fluorite/fluorspar, Graphite, Hematite, Iron/pig iron, Iron nugget, Limestone, Manganese, Saltpetre (Chile or nitratine or soda nitre), Selenium, Silicomanganese, Sponge (directly reduced) iron, Synthetic graphite (manufactured graphite), Tellurium, Vanadium, Zirconium
Metallurgy including alloys and process—Strontium	Celestite
Metallurgy including alloys and process—Tantalum	Columbite, Fluorite-based product (hydrofluoric acid), Fluorite-based product (potassium fluoride), Pyrochlore, Tantalite
Metallurgy including alloys and process—Thorium	Calcium, Magnesium, Monazite
Metallurgy including alloys and process—Tin	Cassiterite (tin-stone or tin-ore), Coal, Fluorite-based product (fluoro-boric acid), Pyrite, Sulphuric acid (pyrites- and sulphur-based product)
Metallurgy including alloys and process—Titanium	Ilmenite, Magnesium, Rare earth metal (mischmetall), Rutile- and anatase-based chemical (titanium tetra-chloride)
Metallurgy including alloys and process—Tungsten	Natural gas, Scheelite, Silicon, Wolframite
Metallurgy including alloys and process—Uranium	Carnotite, Fluorine-based compound (anhydrous hydrogen fluoride), Fluorine-based compound (uranium hexafluoride), Fluorite-based product (fluorine gas), Pitchblende, Soda ash, Sodium

(continued)

Product/process	Metals/minerals/rocks used
Metallurgy including alloys and process—Vanadium	Calcium, Carnotite, Patronite
Metallurgy including alloys and process—Zinc	Borax, Coal, Coke (coal-based product), Pyrolusite (beta-type), Fraklinite, Hemimorphite, Smithsonite, Sphalerite, Sulphuric acid (pyrites- and sulphur-based product), Willemite, Zincite
Metallurgy including alloys and process—Zirconium	Baddeleyite, Sodium, Zircon
Methanol	Methane
Methyl cyclo-pentadienyl manganese carbonyl	Pyrolusite
Metrology	Dimension stone (commercial granite) (*See also* 'standard reference for kilogram and standard reference for metre')
Micanite	Muscovite mica (splittings)
Mica paper	Reconstituted mica (muscovite-based intermediate product)
Microphone	Rock crystal (quartz—gem variety)
Microprocessor chip	Diamond (gem), Ferrite, Indium compound (phosphide), Nickel-coated mica (muscovite-based intermediate product), Quartz, Silane (silicon tetra-hydride), Silicon
Microscope	Calcite, Gypsum (selenite), Muscovite mica (block/film/sheet)
Microwave oven	Ferrite
Microwave-controlling device	Rare earth metal compounds (gadolinium oxide, lanthanum oxide, neodymium oxide)
Microwave transmitter	Muscovite mica (block/film/sheet)
Milk-of-lime	Lime (or quick lime or fat lime)
Mineral jelly/ petroleum jelly/ Vaseline	Petroleum including heavy crude oil and oil shale (refinery product)
Mineral khaki	Chromium sulphate (basic chromite-based chemical)
Mineral wool/glass wool/lime (or quick lime or fat lime) wool/ rock wool/slag wool	Amphibolite, Basalt, Borax, Diabase, Lime (or quick lime or fat lime), Wollastonite
Mischmetall (intermediate product of mixed rare earth metals obtained during metallurgy)	Bastnasite, Gadolinite, Monazite, Xenotime
Missile/projectile	Aluminium, Boron carbide, Cobalt, Magnesium, Muscovite mica (block/film/sheet), Nickel, Niobium, Selenium, Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38)
Moisture indicator	Cobalt chemical (chloride or cobalt blue)
Monel metal	Copper, Iron, Nickel
Monetary reference	Gold

(continued)

Product/process	Metals/minerals/rocks used
Mordant	Antimony-based chemical (tartar emetic), Arsenic-based compounds (white arsenic or arsenous oxide), Cobalt chemical (chloride or cobalt blue), Uranium compounds (salts)
Mortar	Pozzolanic clay, Stratlingite
Motor fuel (or Mo-gas or gasoline)	Natural gas, Petroleum including heavy crude oil and oil shale (refinery product, light distillate)
Moulding	*See* 'foundry'
Mosaic	Crushed stone (assorted and marble dust)
MRI imaging	Rare earth metal (gadolinium)
Mu-metal or permalloy	Copper, Iron, Molybdenum, Nickel
Naphtha (organic chemical)	Coal, Lignite, Petroleum including heavy crude oil and oil shale (refinery product, light distillate)
Naphthalene (organic chemical) extraction	Coal, Lignite, Petroleum including heavy crude oil and oil shale (derivative, slightly unsaturated)
Naphthalene oil (organic chemical) extraction	Coal, Lignite
Natural gas (processing)	Methyl mercaptan or methyl sulphydryl (sulphur-based product)
Naturopathy	Bentonite
Naval brass	Copper, Zinc, Tin (only 1.25 %)
Neutron detection	Boron-10
Neutron generation	Beryllium
Newton's metal	Bismuth, Lead, Tin
Nicol prism in polariscope	Calcite (Iceland spar)
Night illumination device	Cesium, Strontium nitrate, Strontium oxalate, Strontium peroxide
Nickel-coated mica	Muscovite mica (ground/micronized), Nickel
Nimocast	Chromium, Nickel
Nitrided steel	Steel
Nitinol	Nickel, Titanium
Nitric acid	Saltpetre (Chile or nitratine or soda nitre), Saltpetre (ordinary or potassium)
Non-sparking tools	Beryllium, Copper
Nuclear reactor (including control rod, fuel, fuel element cladding, moderator, heat-transfer unit, coolant, radiation shielding etc.)	Antimony (beta form), Barytes, Beryllium, Bismuth, Boron-10, Boron carbide, Cadmium, Calcium, Helium, Lead, Magnesium, Niobium, Perlite (expanded granules), Potassium, Rare earth metals (europium, gadolinium, holmium), Sodium, Synthetic graphite (manufactured graphite), Tungsten, Uranium-233 (converted from thorium), Uranium-235 and its alloys, Uranium compounds (dioxide, carbide, nitrate and sulphate), Vanadium, Zirconium

(continued)

Product/process	Metals/minerals/rocks used
Nuclear reactor (fast breeder)	Plutonium-239, Plutonium carbide, Uranium compound (carbide)
Nuclear waste treatment	Zeolite
Nylon	Toluene, Synthetic zeolite
Odour control	Alum-ammonium (bauxite-based chemical), Aluminium sulphate—iron-free (aluminium hydroxide-based chemical), Nahcolite, Pyrolusite-based chemical (potassium permanganate), Zeolite
Offset printing	Selenium
Oil cloth	*See* 'vinyl sheet'
Oil well	*See* 'drilling'
Onyx flour	Onyx (quartz—gem variety)
Opacifier	Aluminium fluoride (alumina-based chemical), Antimony-based chemical (antimony oxide), Dolomite, Fluorite/fluorspar, Fluorite-based product (aluminium fluoride), Rare earth metals (cerium, yttrium), Rutile and anatase-based product (titanium dioxide), Tin-based chemical (stannic oxide), Zircon, Zirconia
Optical brightener	Aluminium powder
Optical fibre	Boron, Germanium, Indium compounds (antimonide, arsenide, phosphide), Silicone (elastomer/silicon rubber), *also see* 'glass'
Optical instruments (including quarter-wave plate, polariscope)	Calcite (Iceland spar), Muscovite mica (block/film/sheet), Synthetic zeolite, Tourmaline
Optical mirror	Gallium, Indium
Organic compounds and solvents manufacture	Barium hydroxide, Ethylene, Propylene, Selenium compound
Ornament/jewellery/gem	Aqua marine, Diamond (gem), Emerald, Fluorite/fluorspar, Gold, Gypsum (satinspar), Palladium and platinum (platinum group of metals), Phosphorite, Pyrites—marcasite (trade name, not true marcasite), Quartz, Ruby, Rutile, Sapphire, Silver, Tourmaline (achroite, Brazilian sapphire, indicolite, rubellite, schorl, verdelite), Tungsten carbide, White gold
Oscillator	Pyrites, Rock crystal (quartz—gem variety), Silvered mica (muscovite-based intermediate product)
Oxidizing agent	Chromic acid (chromite-based chemical), Pyrolusite (beta type), Pyrolusite-based chemical (potassium permanganate), Selenium compound, Sodium dichromate (chromite-based chemical)
Oxygen-breathing equipment	Muscovite mica (block/film/sheet)
Oxygen/air liquefaction	Helium, Liquefied natural gas (LNG)
Oxygen sensor	Zirconia

(continued)

Product/process	Metals/minerals/rocks used
Packing (including gaskets)	Asbestos (chrysotile, crocidolite), Expanded/exfoliated graphite (graphite-based product), Indium, Silicone (elastomer/silicon rubber), Vermiculite
Paint—Emulsifier	Bentonite
Paint—Extender/ thinner	Calcite, Diatomite, Feldspar, Gypsum, Kaolin (china clay), Perlite (expanded and milled)/Carlita/Dicalite, Pyrophyllite, Pyroxenite, Talc, White spirit
Paint—Filler (for special properties)	Alum-ammonium (bauxite-based chemical), Aluminium sulphate-ferric (bauxite-based chemical), Asbestos (actinolite, amosite, anthophyllite, biotite, crocidolite, tremolite), Bentonite, Crushed stone (slate powder), Diatomite, Gypsum, Muscovite mica (ground/ micronized), Potash group (potassium phosphate), Pyrolusite-based chemical (manganese borate, manganese linoleate, manganese naphthenate, manganese oxalate, manganese resinate), Pyrophyllite, Rare earth metal (gadolinium), Sodium aluminate (bauxite-based chemical), Talc, Tin-based chemical (organo-tin compounds), Vermiculite, Wollastonite, Zinc-based chemical (zinc peroxide), Zirconia
Paint—Lithopone	Barytes
Paint—Luminescent paint	Aluminium powder, Mesothorium, Thorium compound (oxide or thoria)
Paint—Pigment and dye (including ultramarine)	Antimony-based chemicals (antimony chloride, antimony oxide, antimonic sulphide, antimony sulphide), Antimony black, Barium chromate (chromite-based chemical), Barytes, Cadmium sulphide or cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Carbon black, Celestite, Chromic oxide (chromite-based chemical), Chromium sulphate (basic chromite-based chemical), Cobalt chemicals (acetate, aluminate, carbonate, chloride, oxide, sulphate, titanate and double oxide of cobalt and zinc), Copper sulphate, Croccoite, Graphite, Hematite, Ilmenite, Kaolin (china clay), Lead compounds (blue lead, red lead, lead chromate, lead molybdate and white lead), Lime (or quick lime or fat lime), Mercury compound (mercuric oxide and mercury sulphide), Muscovite mica (ground/micronized), Ochre, Orpiment (arsenic trisulphide), Phlogopite mica, Potash group (potassium carbonate), Prussian blue (Turnbull's blue), Pyrites (Copperas/ Melanterite), Pyrolusite (beta-type), Pyrolusite-based chemicals (hydroquinone or quinol benzene, manganese chloride), Quartz, Realgar (arsenic sulphide), Rutile- and anatase-based product (titanium dioxide), Selenium compound, Stibnite, Sulphur, Sulphuric acid (pyrites- and sulphur-based product), Titanium dioxide (rutile-based product), Tungsten bronze (tungsten-based chemical, tungstic oxide or WO_3), Vanadium-based chemicals (ammonium vanadate, vanadium pentoxide), Zinc chromate (chromite-based chemical)
Paint—Primer	Barium nitrate

(continued)

Product/process	Metals/minerals/rocks used
Pancha Dhatu (5-metal alloy)	Brass, Copper, Iron, Lead, Tin
Paper	Alum-ammonium (bauxite-based chemical), Aluminium hydroxide (includes activated alumina), Aluminium sulphate—iron-free (aluminium hydroxide-based chemical), Asbestos (chrysotile), Barytes, Bauxite, Bentonite, Borax, Cadmium sulphide or cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Caustic soda, Diatomite, Dolomite, Gypsum, Kaolin (china clay), Lime (or quicklime or fat lime), Magnesite, Muscovite mica, Precipitated calcium carbonate or PCC (product based on milk-of-lime), Quartz, Rutile- and anatase-based chemicals (titanous chloride and sulphate), Rutile- and anatase-based product (titanium dioxide), Selenium compound, Slaked lime (lime-based product), Sodium aluminate (bauxite-based chemical), Sulphur dioxide (pyrites- and sulphur-based product), Talc, Water glass/liquid glass/sodium silicate, Wax/paraffin wax, Zeolite
Paraffin wax	*See* 'wax'
Pellets	Bentonite, Hematite, Limestone, Siderite (after calcination), Taconite
Pencil/crayon and writing chalk	Chalk, Graphite, Gypsum, Limestone, Kaolin (china clay), Pyrophyllite, Talc
Pentane	Petroleum (refinery product, light distillate, petroleum ethers)
Perfumery (including extraction from flowers)	Aluminium chloride (bauxite-based chemical), Potassium dichromate (chromite-based chemical), White oil, White spirit
Perlon	Toluene, Synthetic zeolite
Pesticide	See 'insecticide'
Petroleum coke	Asphaltic rock/natural bitumen, Petroleum including heavy crude oil and oil shale (refinery product, heavy end)
Petroleum ethers	Petroleum including heavy crude oil and oil shale (refinery product, light distillate)
Petroleum gas (including liquefied petroleum gas or LPG)	Natural gas, Petroleum including heavy crude oil and oil shale (refinery product, light distillate)
Petroleum jelly	*See* 'mineral jelly/petroleum jelly/Vaseline'
Petroleum recovery (secondary)	Natural gas
Petroleum refining	*See* 'purification/refining—petroleum'
Petroleum (synthetic)	*See* 'synthetic petroleum'
Petromax (carbide lamp)	Calcium carbide (lime-based product), Muscovite mica (block/film/sheet)
Pewter	Antimony (beta form), Lead, Tin

(continued)

Product/process	Metals/minerals/rocks used
Pharmaceuticals (including radiopharmaceuticals or radio-nuclides)	Alum-ammonium (bauxite-based chemical), Aluminium carboxylate (bauxite-based chemical), Aluminium chloride (bauxite-based chemical), Aluminium hydroxide gel, Aluminium sulphate- ferric (bauxite-based chemical), Antimony compounds, Arsenic compounds, Attapulgite/fuller's earth, Bentonite, Bismuth compounds, Calcium, Dolomite, Gallium compound (organic salt), Germanium, Gypsum, Kaolin (china clay), Lime (or quick lime or fat lime), Lithium carbonate (lithium-based product), Lithium citrate (lithium-based product), Magnesite, Mercury compound (mercurous chloride or calomel), Mineral jelly/petroleum jelly (petroleum refinery product), Phosphorus (red and yellow), Phosphorus-32, Potash group (caustic potash and potassium fluoride, a fluorite-based chemical), Propylene, Pyrolusite-based chemical (hydroquinone or quinol benzene), Rare earth metals (lutetium-177, yttrium-90), Rubidium iodide, Rutile- and anatase-based product (titanium dioxide), Selenium compound, Silica gel, Sulphuric acid (pyrites- and sulphur-based product), Talc, Tin-based chemical (organo-tin compounds), Vanadium-based chemicals (ammonium vanadate, vanadium pentoxide), White oil, Zirconium phosphate (baddeleyite- and zircon-based chemicals)
Phenol (organic chemical) extraction	Coal, Lignite
Phosphogypsum (byproduct from phosphoric acid manufacturing)	Apatite, Phosphorite, Sulphuric acid
Phosphor (fluorescent substance)	Phosphorus (yellow), Rare earth metals (samarium, yttrium)
Phosphoric acid	Apatite, Phosphorite
Phosphorus recovery	Coke (coal-based product), Phosphorite
Photocopier	*See* 'Xerox machine/photocopier'
Photoelectric cell	Cesium, Thorium
Photography (*see also* 'camera')	Cadmium halides (cadmium-based compound), Cesium, Ferrocene, Potash-chrome alum (chromite-based chemical), Potassium dichromate (chromite-based chemical), Pyrolusite-based chemicals (hydro-quinone or quinol benzene, manganese sulphide), Silver bromide (silver-based chemical), Zirconium
Photographic flashlight	Magnesium, Rhenium, Zirconium
Photometry	Cesium
Photovoltaic/solar cell	Fullerene (manufactured graphite), Gallium compound (arsenide), Silicon, Thallium compound (oxysulphide)
Pig iron	*See* 'iron/pig iron'
Pipe (for construction)	Stoneware clay
Pipe (smoking)	*See* 'smoking pipe'
Pitch (organic chemical)	*See* 'asphalt/bitumen/pitch/tar/coal tar

(continued)

Product/process	Metals/minerals/rocks used
Plant nutrients and their measurement (includes micronutrients)	Caustic magnesia (magnesite-based product), Bauxite, Boron, Cobalt, Diatomite, Dolomite, Dunite, Lignite, Limestone, Magnesite, Natural gas, Peat, Perlite (expanded and milled)/Carlita/Dicalite, Petroleum, Phosphorite, Potash group (caustic potash), Pyrites, Pyrolusite-based chemicals (manganese monoxide, manganese sulphate), Pyroxenite, Quartz, Saltpetre, Saltpetre (Chile), Saltpetre (lime), Shirasu (volcanic eject), Sulphur, Tourmaline, Vermiculite, Zeolite, Zinc-based chemical (zinc sulphate)
Plaster/stucco/putty	Gypsum, Kaolin (china clay), Magnesite, Muscovite mica (ground/micronized), Perlite (expanded and milled)/Carlita/Dicalite, Potash, Water glass/liquid glass/sodium silicate (*see also* 'putty')
Plaster of Paris (POP) mould	Gypsum
Plastics	Alum-ammonium (bauxite-based chemical), Aluminium hydroxide (includes activated alumina), Aluminium sulphate- ferric (bauxite-based chemical), Asbestos (actinolite, chrysotile, tremolite), Ball clay, Bauxite, Crushed stone (slate powder), Feldspar, Kaolin (china clay), Mercury, Muscovite mica (ground/micronized), Perlite (expanded and milled)/Carlita/Dicalite, Potash group (potassium phosphate), Pyrophyllite, Selenium compound, Sulphuric acid (pyrites- and sulphur-based product), Talc, Vermiculite, Wollastonite, *see also* 'resin (synthetic)'
Plumbing	Lead
Plutonium-239 production	Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38)
Poison (for execution and murder including old practices)	Arsenic-based compound (white arsenic or arsenous oxide), Polonium (bismuth-based material), Sulphur dioxide (pyrites- and sulphur-based product)
Polishing	Aluminium chloride (bauxite-based chemical), Bentonite, Chromic oxide (chromite-based chemical), Corundum, Diatomite, Garnet, Limestone, Mineral jelly/petroleum jelly (petroleum refinery product), Ochre, Perlite (expanded and milled)/Carlita/Dicalite, Rare earth metal compounds (cerium oxide, mixed rare earth metal oxides), Silica sand, Silicon carbide (silicon compound), Silicone (oils), Talc, Wax/paraffin wax, Zircon
Pollution control	Nahcolite, Perlite (expanded and milled)/Carlita/Dicalite, Potash group (potassium carbonate), Pyrolusite-based chemical (potassium permanganate)
Polonium	Bismuth
Polyester	Ethylene, Synthetic zeolite
Polythene	Ethylene, Synthetic zeolite
Porous bronze	Copper, Graphite, Tin
Postage stamp glue	Rare earth metal (europium)
Potassium	Potash
Potassium fluoride	Fluorite-based product (hydrofluoric acid)

(continued)

Product/process	Metals/minerals/rocks used
Potassium nitrite—derivative of saltpetre (ordinary or potassium)	Saltpetre (ordinary or potassium)
Potassium permanganate	Pyrolusite
Potassium silicate	Potash, Quartz, Silica sand
Pottery	Pottery clay, Shirasu (volcanic eject)
Poultry feed	*See* 'animal feed'
Precipitated calcium carbonate	Lime (or quick lime or fat lime)
Precision tools	Boron carbide
Preservation (egg, food, fruits, vegetables)	Aluminium chloride (bauxite-based chemical), Lime (or quick lime or fat lime), Peat, Rock salt, Saltpetre, Saltpetre (Chile), Water glass/liquid glass/sodium silicate, Wax/paraffin wax
Preservation (electrical cable)	Asphalt/bitumen/pitch/tar, Wax/paraffin wax
Preservation (meat)	Aluminium chloride (bauxite-based chemical), Potassium nitrite, Saltpetre (Chile or nitratine or soda nitre), Tin
Preservation (metal, surgical instruments)	Aluminium powder, Asphalt/bitumen/pitch/tar, Chromic acid (chromite-based chemical), Hematite, Mercury compound (mercuric oxide), Phosphorite, Pyrolusite-based chemical (manganese phosphate), Sodium chromate hydrated (chromite-based chemical), Silicon carbide/carborandum (silicon compound); Silicon monoxide (silicon compound), White oil
Preservation (paint)	Potash group (potassium meta-silicate)
Preservation (stone)	Wax/paraffin wax
Preservation (timber, hide, leather)	Arsenic-based compounds (calcium, lead and sodium arsenates), Asphalt/bitumen/pitch/tar, Fluorine-based compound (fluoro-silicates of ammonia, magnesium and zinc), Pyrites (Copperas/Melanterite), Rock salt, Sodium dichromate (chromite-based chemical), Water glass/liquid glass/sodium silicate
Printing ink	*See* 'ink (printing)'
Printing type metal	Antimony (beta form), Copper, Lead, Tin
Producer gas	Coal
Prussian blue (Turnbull's blue)	Iron
Purification/refining/cleaning (*see also* water treatment)—Alcoholic drink (including beer)	Diatomite, Sulphur dioxide (pyrites- and sulphur-based product), Zircon
Purification/refining/cleaning (*see also* water treatment)—Caustic soda	Celestite

(continued)

Product/process	Metals/minerals/rocks used
Purification/refining/ cleaning (*see also* water treatment)—Edible oil	Attapulgite/fuller's earth, Bentonite, Diatomite, Tin-based chemical (stannous chloride), Zeolite
Purification/refining/ cleaning (*see also* water treatment)—Food and fruits	Sulphur dioxide (pyrites- and sulphur-based product)
Purification/refining/ cleaning (*see also* water treatment)—Gases (including coal gas, fluorine, natural gas, oxygen)	Attapulgite/fuller's earth, Bauxite, Bog iron ore, Fluorine-based compound (sodium fluoride), Nickel, Zeolite
Purification/refining/ cleaning (*see also* water treatment)—Petroleum	Aluminium chloride (bauxite-based chemical), Aluminium hydroxide (includes activated alumina), Nickel, Palladium (platinum group of metals), Petroleum (crude/natural), Rare earth metal compounds (cerium oxide, lanthanum oxide, neodymium oxide, praseodymium oxide), Sulphuric acid (pyrites- and sulphur-based product)
Purification/refining/ cleaning (*see also* water treatment)—Toxic liquids	Aero-gel/aero-sil/silica aerogel, Diatomite, Perlite (expanded and milled)/Carlita/Dicalite, Water glass/liquid glass/sodium silicate, Zeolite
Putty	Limestone (*see also* 'plaster/stucco/putty')
Pyridine (organic chemical) extraction	Coal, Lignite
Pyrolytic graphite	Graphite
Pyrotechnics (fireworks)	Antimony (beta form), Borax, Boron, Kaolin (china clay), Magnesium, Sulphur, Strontium nitrate, Strontium oxalate, Strontium peroxide, Sulphur, Zinc
Quartz bulb	*See* 'halogen/quartz bulb'
Quartz clock	Rock crystal (quartz—gem variety)
Quaternary casting alloy	Magnesium (90 % along with a little of zinc and zirconium)
Radar	Garnet, Iron, Muscovite mica (block/film/sheet), Rare earth metals (lanthanum, yttrium), Rare earth metal compounds (gadolinium oxide, lanthanum compound)
Radiation pyrometer	Muscovite mica (block/film/sheet)
Radiator antifreeze	Ethylene
Radio (includes bulb, valve)	Cesium, Ferrite, Magnesite, Magnesium, Molybdenum, Muscovite mica (block/film/sheet), Pyrites, Rhenium, Rubidium, Rock crystal (quartz—gem variety), Saltpetre (lime), Selenium, Tantalum, Thorium
Radio bulb	Thorium
Radiography	*See* 'X-ray/radiation/radiography'

(continued)

Product/process	Metals/minerals/rocks used
Radiotherapy (including shielding)	Cobalt-60, Gallium-72 (isotope of gallium), Mesothorium, Molybdenum-99, Phosphorus-32, Rare earth metals (lutetium-177, samarium-153, yttrium-90), Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38)
Railway coach/wagon	Aluminium, Aluminium foam
Rayon (includes manufacturing machinery)	Antimony-based chemical (titanyl chloride antimony trichloride), Carbon disulphide (sulphur-based product), Gold, Platinum and rhodium (platinum group of metals), Rutile- and antimony-based chemical (titanyl chloride antimony trichloride complex)
Rechargeable cell	*See* 'cell (battery)'
Reconstituted mica	Muscovite mica (scrap)
Record player	Diamond
Recording tapes (audio and video)	*See* 'cassette'
Rectifier	Germanium, Mercury, Selenium, Tantalum, Tungsten
Reductant	*See* 'deoxidizer'
Refinery (oil)	Muscovite mica (block/film/sheet), perlite
Refining	*See* 'purification'
Refractory	Alumina, Andalusite, Baddeleyite/zirconia, Bauxite, Bentonite, Chromite, Copper (in Romelt steel-smelting furnace), Corundum, Diaspore, Diatomite, Dolomite, Dunite, Feldspar, Fireclay, Forsterite, Graphite, Kaolin (china clay), Kyanite, Magnesite, Perlite (expanded and milled)/Carlita/Dicalite, Pyrophyllite, Pyroxenite, Fused quartz, Quartzite, Serpentinite, Silicon carbide (carborandum), Sillimanite, Talc/steatite, Vermiculite, Zircon/zirconia
Refrigeration (including old uses)	Fluorine-based compound (chlorofluorocarbon), Rock salt (frozen solution in water), Sulphur dioxide (pyrites- and sulphur-based product), Zeolite
Refrigerator (testing)	Helium
Resin (synthetic)/plastics	Ethylene (*See also* 'plastics')
Rhenium diboride (ultra-hard material)	Rhenium
Rheostat	Constantan
Rip-rap	Crushed stone
Road metal/road aggregate (including paving, road making)	Alumina, Asphalt/bitumen/pitch/tar, Asphaltic rock/natural bitumen, Crushed stone (basalt, dolerite, granite, limestone, marble flour)
Robotics	Diamond (gem), Nickel
Rocket	*See* 'space technology'
Rocket fuel (including propellant)	Aluminium powder, Borax-based chemical (boron hydride), Boron, Helium, Lithium perchlorate (lithium-based product), Saltpetre (Chile or nitratine or soda nitre), Saltpetre (ordinary or potassium)
Rock wool	*See* 'mineral wool'
Rodenticide	Thallium compound (sulphate)

(continued)

Product/process	Metals/minerals/rocks used
Roofing material (including asphalted cardboard felting)	Aluminium, Asbestos (chrysotile), Asphaltic rock/natural bitumen, Crushed stone (slate granules), Monel metal, Muscovite mica (ground/micronized), Peat, Tin
Rose's metal	Bismuth, Lead, Tin
Rubber (including synthetic rubber)	Aero-gel/aero-sil/silica aerogel, Alum-ammonium (bauxite-based chemical), Aluminium hydroxide (includes activated alumina), Aluminium sulphate- ferric (bauxite-based chemical), Antimony-based chemicals (antimonic sulphide, antimony sulphide), Ball clay, Barium chromate (chromite-based chemical), Barytes, Bauxite, Bentonite, Cadmium sulphide or cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Calcite, Carbon black, Chalk, Clay (ordinary), Crushed stone (slate powder), Diatomite, Gypsum, Ethylene, Kaolin (china clay), Lead compounds (oxides—PbO, PbO_2 and Pb_3O_4), Limestone, Magnesite, Muscovite mica (ground/micronized), Pottery clay, Pyrophyllite, Quartz, Rock salt (only for synthetic rubber), Rutile- and anatase-based product (titanium dioxide), Selenium, Selenium compound, Stibnite, Sulphur, Talc, Tellurium, Wollastonite, Zinc-based chemical (zinc oxide), Zinc chromate (chromite-based chemical), Zirconia
Rust-proof coating (temporary)	Bismuth (low-melting alloys, washable with hot water)
Saccharin	Phosphorus (red and yellow)
Safety fuse (fuse wire)	Bismuth, Cadmium, Lead, Tin
Safety plug	Bismuth, Cadmium, Tin
Salt (edible)	*See* 'edible salt'
Salt cake (sodium sulphate)	Rock salt
Sand blasting	Building/river sand, Garnet, Staurolite
Sand casting	Magnesium (alloys)
Sanitary ware (unfired) including bathtubs, kitchen platforms, wash basins etc.	Dimension stones (commercial granite, commercial limestone, commercial marble, commercial sandstone, commercial slate), Talc
Satellite	*See* 'space technology'
Scintillation counter	Sodium iodide, Thallium
Scotch whisky	Peat
Sealing/lining	Aluminium hydroxide (includes activated alumina), Asbestos (chrysotile), Attapulgite/fuller's earth, Bauxite, Bentonite, Crushed stone (slate powder), Diatomite, Expanded/exfoliated graphite (graphite-based product), Graphite/carbon fibre (manufactured graphite), Indium, Kaolin (china clay), Muscovite mica (ground/micronized), Precipitated calcium carbonate or PCC (intermediate product based on milk-of-lime), Silane (silicon tetra-hydride), Silicone (elastomer/silicon rubber), Talc, Tungsten, Vermiculite, Water glass/liquid glass/sodium silicate
Searchlight	Phlogopite mica, Rare earth metal compound (cerium oxide), Rhodium (platinum group of metals)

(continued)

Product/process	Metals/minerals/rocks used
Seawater magnesia	Dolomite, Limestone
Seeded aluminium hydroxide gel	Aluminium hydroxide (includes activated alumina), Monel metal
Semiconductor (including base)	Boron, Diamond, Fluorine-based compound (fluoro-carbon), Gallium compound (arsenide), Indium compounds (antimonide, arsenide, phosphide), Molybdenum, Phosphorus (red and yellow), Rare earth metals (lanthanum, yttrium), Zirconia
Sericulture (including weighting agent for silk)	Tin-based chemical (stannous chloride)
Sewerage pipe	Stoneware clay
Ship (under-sea components and their protection)	Copper (in the form of alloys with minor quantities of other metals)
Sialon (ceramics)	Clay (ordinary), Coal, Fireclay
Signalling device	Barium oxide, Cesium, Magnesium, Strontium nitrate, Strontium oxalate, Strontium peroxide, Thallium compound (bromo-iodide)
Silane (silicon tetra-hydride)	Trichlorosilane
Silica gel	Silicic acid (silicon compound)
Silica flour	Silica sand
Silica sand beneficiation	Rutile- and anatase-based chemicals (titanous chloride and sulphate)
Silica sol	Quartz
Silicic acid	Water glass/liquid glass/sodium silicate
Silicon carbide	Quartz, Silane, Silica sand, Silicon
Silicon recovery	Quartz
Silico-manganese	Coke (coal-based product), Dolomite, Limestone, Psilomelane
Silicone (elastomer/silicone rubber, resins, silicone oils and silli-putty)	Silicon, Borax-based chemical (boric acid)
Silicon nitride	Quartz, Silica sand, Silicon, Trichlorosilane
Silli-putty	*See* 'silicone'
Silvered mica	Muscovite mica (block/film/sheet)
Silver plate	Nickel, Silver
Silverware	Cadmium, Silver
Silviculture	Zeolite
Sinters	Anthracite, Coal, Hematite, Limestone
Skin care	Aqua marine, Corundum (ruby and sapphire), Diamond (gem), Emerald, Rutile- and anatase-based product (titanium dioxide), White oil
Sky-writing (for advertisement etc.)	Rutile- and anatase-based chemical (titanium tetra-chloride)
Slag granulation	Perlite (natural)

(continued)

Product/process	Metals/minerals/rocks used
Slag wool	*See* 'mineral wool'
Slaked lime	Lime (or quick lime or fat lime)
Smart wire	Nickel
Smoke bomb	Antimony (alpha form), Antimony-based chemical (antimony chloride), Saltpetre (ordinary or potassium)
Smoke inhibitor	Tin-based chemical (zinc hydroxyl stannate and stannate)
Smoke screen	Rutile- and anatase-based chemical (titanium tetra-chloride)
Smoking pipe	Clay (pipe)
Sniperscope	Cesium
Snooperscope	Cesium
Soaps/detergents/toilet powder (including synthetic detergent)	Aluminium powder, Bentonite, Benzene, Borax-based chemical (sodium perborate), Cadmium sulphide or cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Ethylene, Gypsum, Kaolin (china clay), Perlite (expanded and milled)/Carlita/Dicalite, Phosphoric acid-based products (sodium tri poly-phosphate), Potash group (caustic potash, potassium carbonate and phosphate), Selenium compound, Soda ash or soda (sodium carbonate), Synthetic zeolite, Water glass/liquid glass/sodium silicate, Wax/paraffin wax, Zeolite, Zeolite (synthetic)
Soda ash or soda (sodium carbonate)	Limestone, Rock salt, Trona
Soda beverage	Phosphoric acid
Sodium aluminate	Bauxite
Sodium bicarbonate	Limestone
Sodium hexa-meta phosphate or calgon (phosphoric acid product)	Sodium ammonium hydrogen phosphate (phosphoric acid-based product)
Sodium lamp	Niobium, Phosphorite, Sodium
Sodium silicate	*See* 'water glass/liquid glass'
Soil conditioning	Apatite, Crushed stone (marble flour), Dolomite, Dunite, Gypsum, Lime (or quick lime or fat lime), Magnesium sulphate—anhydrous (magnesite-based product), Peat, Phosphorite, Potash group (potassium chloride, schoenite and sulphate), Pyrites, Pyroxenite, Shirasu (volcanic eject), Sulphur, Vermiculite, Zeolite
Solar cell	*See* 'photovoltaic cell'
Solar heating	Zeolite
Soldering	Aluminium fluoride (alumina-based chemical), Antimony (beta form), Arsenic, Borax, Indium, Lead, Silver, Thallium, Tin
Solvent (industrial)	Carbon disulphide (sulphur-based product)
Solvent (organic)	Ethylene/olefin
Space technology (includes satellite, rocket, spacecraft, space shuttle, lunar vehicle)	Aluminium, Boron (boron-containing metal-matrix composite), Diamond (gem), Fullerene (manufactured graphite), Gallium compound (arsenide), Helium, Polonium (bismuth-based material), Pyrolytic graphite (manufactured graphite), Lithium, Niobium, Platinum (platinum group of metals), Titanium, Weldite (aluminium-lithium alloy)

(continued)

Product/process	Metals/minerals/rocks used
Spark plug	Barium, Iridium, Palladium and platinum (platinum group of metals), Rhenium, Tungsten
Speaker	*See* ‘loud speaker’
Spectrometer	Thallium compound (bromo-iodide)
Spectrophotometer	Diamond (gem), Rhenium
Speed governor	Tungsten
Spiegeleisen	Coke (coal-based product), Dolomite, Limestone, Psilomelane (low-grade)
Spinodal alloy	Copper, Nickel, Tin
Sponge iron (directly reduced iron)	Coal, Dolomite, Hematite, Limestone, Natural gas
Sporting goods	Graphite/carbon fibre (manufactured graphite)
Sporting gun	Antimony (alpha form), Antimony-based chemical (antimony chloride)
Sports car	Aluminium, Boron (boron-containing metal-matrix composite), Fullerene (manufactured graphite), Titanium
Stainless steel (including its manufacturing process)	Ferrochrome (including charge chrome and high-, medium- and low-carbon ferrochrome, silico-chrome), Ferromanganese, Ferro-niobium, Nickel, Steel, Titanium
Standard reference for ‘kilogram’ or International Prototype Kilogram (IPK)	Palladium and platinum (platinum group of metals)
Standard reference for ‘metre’	Cesium
Static electricity (control device)	Polonium (bismuth-based material)
Statuary	*See* ‘art work’
Steam pipes	*See* ‘boiler’
Steel	Ferromanganese, Iron, Limestone
Stellite	Chromite, Cobalt, Manganese, Molybdenum, Nickel, Tungsten
Sterilization	Cobalt-60, fluorine-based compound (chlorofluorocarbon), Uranium
Stoneware for chemical	Stoneware clay
Stoneware crockery	Stoneware clay
Storage	*See* ‘handling’
Stowing (mine)	Building/river sand, Coal usage waste (fly ash)
Strontium carbonate	Celestite
Strontium hydroxide	Celestite, Strontianite
Strontium nitrate	Celestite, Strontianite
Strontium peroxide	Celestite, Strontianite
Strontium titanate	Celestite, Strontianite
Stucco	*See* ‘plaster’
Submarine	Muscovite mica (block/film/sheet), Titanium, Uranium-235

(continued)

Product/process	Metals/minerals/rocks used
Sugar	Barium hydroxide, Milk-of-lime (lime-based product), Pyrolusite-based chemical (potassium permanganate), Rutile- and anatase-based chemicals (titanous chloride and sulphate), Strontianite, Sulphur
Sugar of lead	Lead
Sulphur recovery	Asphaltic rock/natural bitumen, Coal, Diatomite, Natural gas, Petroleum including heavy crude oil and oil shale (refinery product)
Sulphur dioxide	Pyrites, Sulphur
Sulphuric acid manufacturing	Anhydrite, Gypsum, Pyrites, Sulphur dioxide (pyrites- and sulphur-based product), Vanadium-based chemical (vanadium pentoxide)
Sulphurous acid manufacturing	Sulphur dioxide (pyrites- and sulphur-based product)
Superconductor	Bismuth compound (oxide), Borax-based compound (magnesium diboride), Boron, Nickel, Niobium, Rhenium, Silver, Tin, Titanium
Surgery/surgical material (including dressing)	Chromium, Cobalt, Gypsum, Iridium (platinum group of metals), Magnesium, Molybdenum, Nickel, Niobium (powder), Nitinol, Palladium and platinum (platinum group of metals), Peat, Rare earth metal (holmium), Silicone (silli-putty), Silver, Tantalum, Zirconium
Surgical reamers	Diamond (industrial)
Switch board	Dimension stones (commercial slate)
Synthetic borax	Colemanite
Synthetic cryolite	Bauxite, Clay, Fluorite-based product (fluoro-silicic acid)
Synthetic diamond	*See* ‘artificial/synthetic diamond’
Synthetic/artificial gems (includes their manufacturing)	Borax, Gallium, Garnet, Rare earth metal (gadolinium) (*see also* ‘artificial diamond’)
Synthetic garnet	*See* ‘garnet (synthetic)’
Synthetic graphite	Graphite
Synthetic/imitation marble	Aluminium hydroxide (includes activated alumina), Antimony-based chemical (antimony oxide), Calcite, Gypsum, Onyx flour (quartz—industrial variety), Silica flour (quartz—industrial variety), Talc
Synthetic manganese dioxide	*See* ‘electrolytic manganese dioxide and chemically activated manganese dioxide’
Synthetic petroleum	Coal, Cobalt, Natural gas, Thorium
Synthetic ruby	Aluminium
Synthetic rutile	Ilmenite
Synthetic zeolite	Kaolin (china clay), Kimberlite
Tar	*See* ‘asphalt/bitumen/pitch/tar/coal tar’
Talcum powder	*See* ‘cosmetics’
Telecommunication	*See* ‘communication’
Telephone (including portable ones)	Ferrite, Gallium, Palladium and platinum (platinum group of metals), Rock crystal (quartz—gem variety)
Telescope lens	Rare earth metal (lanthanum)

(continued)

Product/process	Metals/minerals/rocks used
Television (camera, picture tube, screen, filter)	Cadmium phosphor (cadmium-based compound), Cesium, Ferrite, Germanium, Potash group (potassium carbonate and meta-silicate), Rare earth metals (europium, terbium, yttrium), Rare earth metal compounds (cerium oxide, erbium oxide, europium oxide, neodymium oxide, praseodymium oxide, yttrium oxide), Selenium, Silver
Terne plating (for roofing sheet)	Lead, Tin
Ternary casting alloy	Magnesium (93–97 % along with a little of zinc and zirconium)
Terracotta articles	Terracotta clay
Terrazzo	Crushed stone (marble chips)
Terylene	Ethylene, Synthetic zeolite
Tetraethyl lead	Lead, Sodium
Textile (includes de-staining agent, machine)	Alum-ammonium (bauxite-based chemical), Aluminium carboxylate (bauxite-based chemical), Aluminium sulphate- ferric (bauxite-based chemical), Asbestos (amosite, chrysotile, crocidolite), Barium chloride, Borax, Cadmium sulphide or cadmium yellow and cadmium sulpho-selenide or cadmium red (cadmium-based compounds), Calcite, Gypsum, Kaolin (china clay), Magnesium, Potash-chrome alum (chromite-based chemical), Potash group (potassium carbonate), Pyrolusite-based chemical (manganese chloride), Rutile- and anatase-based chemicals (titanous chloride and sulphate), Rutile- and anatase-based product (titanium dioxide), Slaked lime (lime-based product), Sodium dichromate (chromite-based chemical), Sodium tungstate, Sulphur dioxide (pyrites- and sulphur-based product), Talc, Tin-based chemical (organo-tin compounds), Uranium compounds (salts), Vanadium-based chemicals (ammonium vanadate, vanadium pentoxide), Zirconium
Thermal dosimeter (for measuring radiation)	Diamond (gem), Tourmaline
Thermal power generation	Anthracite, Coal, Lignite, Methane, Natural gas
Thermal power plant	Muscovite mica (block/film/sheet)
Thermal regulator	Muscovite mica (block/film/sheet)
Thermistor	Germanium
Thermocouple	Constantan, Iridium, Palladium, Platinum, Rhenium, Rhodium (platinum group of metals)
Thermometer	Gallium (500–1,200 °C range), Mercury, Fused quartz, Thallium
Thermonuclear reactor (including fusion power generation, hydrogen bomb)	Helium (helium-3), Lithium deuteride (lithium-based product)
Thermoplastics/ thermoset	Muscovite mica (ground/micronized), Phlogopite mica
Thermoset	*See* ‘thermoplastic’
Tile (fired)	*See* ‘ceramics’
Tile, roofing	Roofing tile clay

(continued)

Product/process	Metals/minerals/rocks used
Tile (unfired)	Crushed stone (marble dust), Gypsum, Magnesite
Tinning (or tin-plating)	Sulphuric acid (pyrites- and sulphur-based product), Tin
Titanium carbide	Titanium
Titanium dioxide (rutile-based product)	Aluminium chloride (bauxite-based chemical), Anatase, Rutile, Synthetic rutile, Zinc-based chemical (zinc peroxide)
Toilet powder	*See* 'soap'
Toluene (aromatic organic chemical)	Coal, Lignite, Petroleum including heavy crude oil and oil shale
Tools (high-performance ones made of metal, ceramic and diamond)	Isostatic graphite mould
Tool steel	Ferrochrome (including charge chrome and high-, medium- and low-carbon ferrochrome, silico-chrome)
Tooth paste/powder	Borax, Corundum, Diatomite, Fluorine-based compound (sodium fluoride), Fluorine-based compound (sodium mono-fluoro-phosphate), Fluorine-based compound (stannous fluoride), Fluorite-based product (fluorine gas), Kaolin (china clay), Phosphoric acid-based products (di-sodium phosphate, sodium mono-phosphate, sodium pyrophosphate, sodium tri-poly-phosphate, tetra-sodium phosphate, tri-sodium phosphate), Pyrophyllite, Saltpetre (ordinary or potassium)
Touchstone for gold	Jasper
Toys	Barytes, Silicone (silli-putty)
Tracer bullet	Strontium nitrate, Strontium oxalate, Strontium peroxide
Traction sand	Building/river sand, Silica fume/silica dust/fluffy silica/micro-silica
Transducer	Niobium pentoxide (niobium compound), Rock crystal (quartz—gem variety)
Transistor	Gallium compound (arsenide), Germanium, Graphene (graphite-based product), Titanium
Transportation fuel (air, ocean, river, road)	Aviation turbine fuel (petroleum refinery product, middle distillate), Diesel high speed (petroleum refinery product, middle distillate), Heavy fuel oil (petroleum refinery product, heavy end), Methane (abandoned and working mine, coal bed and coal mine ventilation air methane), Motor fuel or Mo-gas (petroleum refinery product, light distillate), Natural gas, Petroleum (crude/natural), Uranium-235 (ocean transport)
Trichlorosilane	Silicon
Tube, collapsible	Antimony (beta form), Lead, Tin
Tungsten carbide	Niobium carbide (niobium compound), Tungsten
Turnbull's blue	*See* 'Prussian blue'
Turquoise green	Cobalt (titanate)
Type metal	*See* 'Printing type metal'
Ultra-hard materials	Boron carbide, Boron nitride/borazon/wurtzite, Lonsdaleite, Rhenium diboride
Ultrasonography	Rock crystal (quartz—gem variety)

(continued)

Product/process	Metals/minerals/rocks used
Underground coal mine	Dolomite
Uranium-233 recovery	Thorium
Uranium-235 recovery	Uranium metal
Uranium-238 recovery	Uranium metal
Utensils (including tableware, cutlery, silverware)	Aluminium, Copper, German silver, Rhodium (platinum group of metals), Silver
Vacuum device	Barium, Calcium, Cesium, Magnesium, Niobium, Rubidium, Rare earth metal (lanthanum), Tantalum, Zirconium
Vanaspati (butter-like fat of vegetable origin)	Borax, Siderite (after calcination)
Varakh (thin edible cover on sweets)	Silver
Varnish	Asphalt/bitumen/pitch/tar, Pyrolusite-based chemical (manganese borate, manganese linoleate, manganese naphthenate, manganese oxalate, manganese resinate), Slate powder (crushed stone)
Vaseline	*See* ‘mineral jelly/petroleum jelly/Vaseline’
Vegetable oil processing	Pyrolusite-based chemical (manganese borate, manganese linoleate, manganese naphthenate, manganese oxalate, manganese resinate)
Vermicide	Phosphorus (yellow)
Vibration damping	Asbestos (chrysotile), Lead
Video cassette	*See* ‘cassette’
Video tape recorder	*See* ‘cassette player’
Vinyl sheet/linoleum/oil cloth (includes PVC)	Asbestos (chrysotile), Barium hydroxide, Bentonite, Barium chromate (chromite-based chemical), Chromic oxide (chromite-based chemical), Ethylene, Tin-based chemical (organo-tin compound), Zinc chromate (chromite-based chemical)
Viscosity increasing	Bentonite
Vitamins	Phosphorus (red and yellow)
Vodka	Asbestos (chrysotile)
Wall paper	Muscovite mica (ground/micronized)
Waste treatment	Zeolite
Watch	Osmium and palladium (platinum group of metals)
Watch/clock dial (luminescent)	Radium
Water filter candle	Quartz, Silica sand
Water gas (blue water gas)	Coal, Coke (coal-based product)
Water gas, carbureted	Coal
Water glass/liquid glass (sodium silicate)	Diatomite, Quartz, Silica sand
Waterproofing (includes waterproof coating on nylon, paper, rayon, silk, wood, wool etc.)	Alum-ammonium (bauxite-based chemical), Aluminium carboxylate (bauxite-based chemical), Aluminium sulphate- ferric (bauxite-based chemical), Rutile- and anatase-based chemical (alkyl titanate), Silicone (elastomer/silicone rubber and oils), Wax/paraffin wax (petroleum refinery product)

(continued)

Product/process	Metals/minerals/rocks used
Water sprinkler, automatic	Bismuth, Cadmium, Tin
Water potability test	Gold (nano-chip)
Water treatment (including sewerage water and fluoridation, fluorination and arsenic removal)	Alum-ammonium (bauxite-based chemical), Aluminium chloride (bauxite-based chemical), Aluminium sulphate—iron-free and ferric (aluminium hydroxide-based and bauxite-based chemicals), Barium chloride, Calcite, Diatomite, Dolomite, Fluorite-based product (fluorine gas), Fluorite-based product (fluoro-silicic acid), Glauconite, Lime (or quick lime or fat lime), Magnetite (nano-crystals), Phosphoric acid-based products (di-sodium phosphate, sodium aluminate (bauxite-based chemical), sodium mono-phosphate, sodium pyrophosphate, sodium tri-poly-phosphate, tetra-sodium phosphate, tri-sodium phosphate), Potash group (potassium phosphate), Pyrolusite-based chemical (potassium permanganate), Slaked lime (lime-based product), Soda ash (sodium carbonate), Water glass/liquid glass/sodium silicate, Zeolite
Wax (paraffin wax)	Petroleum including heavy crude oil and oil shale (refinery products)
Weaponry (including nuclear)	ALON (aluminium oxy-nitride), Aluminium, plutonium-239
Weed killer	Arsenic-based compounds (calcium arsenate)
Welding/welding rod (including ceramic welding, coating)	Aluminium fluoride (alumina-based chemical), Anatase, Bentonite, Bauxite, Borax, Calcium carbide, Cryolite, Feldspar, Hematite, Lithium chloride (lithium-based product), Lithium fluoride (lithium-based product), Magnesite, Muscovite mica (ground/micronized), Potash group (potassium meta-silicate), Quartz, Rutile, Silica sand, Thorium, Tungsten, Water gas (coal-based product), Water gas (carbureted, coal-based product)
Weldite	Aluminium, Lithium
White carbon	Graphite
White gold	Gold, Nickel, Palladium (platinum group of metals)
White oil	Petroleum including heavy crude oil and oil shale (refinery products)
White metal	Antimony (beta form), Lead
White spirit	Petroleum including heavy crude oil and oil shale (refinery products)
Window	Muscovite mica (block/film/sheet)
Wine/winery	Rock salt, Sulphur dioxide (pyrites- and sulphur-based product)
Wine bottle cap	Tin
Winery	Sulphur dioxide (pyrites- and sulphur-based product)
Wire drawing (die)	*See* 'die (for wire drawing)'
Wood's metal	Bismuth, Cadmium, Lead, Tin
Wool	Aluminium chloride (bauxite-based chemical), Rutile- and anatase-based chemicals (titanous chloride and sulphate), Sulphur dioxide (pyrites- and sulphur-based product)
Writing chalk	*See* 'pencil/crayon and writing chalk'
Writing slate	Dimension stones (commercial slate)

(continued)

Product/process	Metals/minerals/rocks used
Wrought iron	Iron/pig iron
Xerox machine/ photocopier	Selenium
X-ray/radiology/ radiography	Barytes, Beryllium, Pyrolytic graphite (manufactured graphite), Lead (for shielding), Lead glass, Rare earth metals (europium, gadolinium, terbium, yttrium), Sodium tungstate, Thorium, Tungsten, Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38)
Xylene (organic chemical)	Coal, Lignite, Petroleum including heavy crude oil and oil shale (derivative, slightly unsaturated)
Xylenols (organic chemical)	Coal, Lignite, Petroleum
Zari	Gold, Silver
Zari, imitation	Copper, Silver
Zeolite (synthetic)	*See* 'synthetic zeolite'
Zeoponic materials (chemically modified natural zeolite with enhanced efficiency)	Zeolite
Zinc-beryllium silicate	Beryllium, Zinc

Chapter 10
Annexure II: Mineral-Wise Uses of Metals, Minerals and Rocks

(***Hardness values are on Mohs scale***)

Mineral/metals/rocks	Product/process
Aero-gel/aero-sil/silica aerogel	Catalyst; Construction (for solar heating); Desiccation; Insecticide/pesticide/germicide/fungicide (carrier); Insulator (heat); Purification/cleaning (toxic liquids); Rubber (including synthetic rubber)
Agate	*See* 'quartz—gem varieties'
Alnico (alloy of iron with aluminium, nickel, cobalt)	Magnet (permanent)
ALON (aluminium oxy-nitride)	Aircraft; Electrochemical boring; Weaponry
Alumina (includes calcined, sintered and fused alumina)	Abrasive/grinding (wheel, paper, cloth), Catalyst; Cement (calcium aluminate refractory cement); Ceramics (including fired tiles, composites, porcelain); Grinding; Metallurgy (aluminium); Refractory (alumina-graphite, alumina-zirconia-silica, calcined and sintered alumina, chrome alumina); Road metal/road aggregate
Alumina-based chemical—Aluminium fluoride	Aluminium silicate fibre; Ceramics; Enamel; Foundry (metal casting); Glass (optical and special glasses); Metallurgy (aluminium); Opacifier; Soldering, Welding
Alumina-based chemical—Aluminium nitrate mono-hydrate	Alumina (electrically insulating)
Alumina (electrically insulating)	Actinides extraction; Cathode ray tube; Electric equipments (motor/generator/transformer, portable transformer); Insulator (electrical)—wrapping paper

(continued)

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Mineral/metals/rocks	Product/process
Aluminium and its alloys	Aircraft; Alnico (alloy of iron with aluminium, nickel, cobalt); ALON (aluminium oxy-nitride); Aluminium bronze; Aluminium foam; Aluminium powder; Artificial diamond (in combination with yttrium and garnet); Automotive bodies/parts; Board/panel; Canning/packaging; Capacitor; Ceramics (metal-matrix composite in combination with boron); Die casting; Electrical transmission; Electronic equipment; Foils (for wrapping food etc.); Handling/storage (chemicals, paints etc.); Laser (in combination with neodymium, yttrium and garnet); Marinel (multi-metal alloy); Missile; Laser/maser; Railway coach/wagon; Roofing material; Space technology (including rocket, satellite, spacecraft); Sports car; Synthetic ruby (in combination with yttrium and garnet); Utensils; Weaponry (mortar barrel mounting); Weldite
Aluminium foam	Automotive bodies; Construction (building structures); Railway coaches/wagons
Aluminium hydroxide (includes activated alumina)	Abrasive/grinding (for soft surfaces like plastic); Adhesive; Catalyst; Desiccation; Fertilizer; Paper; Plastics; Purification/refining/cleaning (petroleum); Rubber (including synthetic rubber); Sealing/lining; Seeded aluminium gel; Synthetic marble
Aluminium hydroxide-based chemical—Aluminium nitrate mono-hydrate	Alumina (electrically insulating)
Aluminium hydroxide-based chemical—Aluminium sulphate (iron-free)	Aluminium hydroxide gel; De-staining; Leather; Odour control; Paper; Water treatment
Aluminium hydroxide gel	Pharmaceuticals
Aluminium powder	Aluminothermic smelting process; Epoxy; Explosion/explosive/pyrotechnics (blasting agent); Magnet (permanent magnet, in alloy with cobalt, iron and nickel); Metallurgy (molybdenum); Optical brightener; Paint (pigment and dye); Preservation (metal); Rocket fuel; Soaps/detergents/toilet powder (mildly abrasive additive to biodegradable detergent)
Amazonite	*See* ‘Feldspar (amazonite)’
Amber	Gem; Gemmotherapy; Ornament/jewellery
Amblygonite (lithium mineral)	Metallurgy (lithium)
Amethyst	*See* ‘quartz—gem varieties’
Ammonia	Fertilizer
Amphibolite	Mineral wool/rock wool
Anatase	Chemicals (*see* ‘rutile-based chemicals’); Titanium dioxide (*see* ‘rutile-based product’); Welding
Anatase-based chemicals	*See* ‘rutile-based chemicals’
Anatase-based product	*See* ‘rutile-based product’
Andalusite	Gem; Gemmotherapy; Ornament/jewellery; Refractory

(continued)

Mineral/metals/rocks	Product/process
Anhydrite	Fertilizer; Sulphuric acid
Anthracite	Calcium carbide; Coke; Domestic heating; Industrial heating; Lime (or quick lime or fat lime) burning; Metallurgy (iron); Sinters; Thermal power generation
Antimony (alpha form)	Smoke bomb; Sporting gun
Antimony (beta form)	Babbitt metal (alloy with mainly tin and copper); Britannia metal (alloy with tin); Bullet/shot/shell; Cable sheath; Cell (battery); Chemicals (*see below*); Nuclear reactor (alloy with uranium); Pewter (alloy with copper and tin); Printing type metal (alloy with copper, lead and tin); Pyrotechnics (fireworks); Soldering; Tube (collapsible); White metal (alloy with lead)
Antimony-based chemical—Antimony chloride	Fire extinguishing; Paint (pigment); Smoke bomb; Sporting gun
Antimony-based chemical—Antimony oxide (antimony white)	Enamel; Opacifier; Paint (pigment); Synthetic/imitation marble
Antimony-based chemical—Antimonic sulphide (Sb_2S_5)	Paint (pigment); Rubber
Antimony-based chemical—Antimony sulphide/antimony vermillion (chemically prepared Sb_2S_3)	Matches; Paint (pigment); Rubber
Antimony-based chemical—Tartar emetic (Potassium antimony tartarate)	Medical application; Mordant
Antimony-based chemical—Titanyl chloride antimony trichloride complex	Rayon
Antimony black (chemically or electrically deposited from antimony solution)	Paint (pigment)
Apatite	Gem; Gemmotherapy; Ornament/jewellery; Phospho-gypsum (byproduct from phosphoric acid manufacturing); Phosphoric acid; Soil conditioner
Apatite (asparagus stone)	Gem; Gemmotherapy; Ornament/jewellery
Apatite (lasurapalite)	Gem; Gemmotherapy; Ornament/jewellery
Apatite (manganapalite)	Gem; Gemmotherapy; Ornament/jewellery

(continued)

Mineral/metals/rocks	Product/process
Apatite (moroxite)	Gem; Gemmotherapy; Ornament/jewellery
Apophyllite	Gem, Ornament/jewellery
Aqua marine	Gem; Gemmotherapy; Ornament/jewellery; Skin care
Argentite	Metallurgy (silver)
Arsenic	Bullet/shot/shell (alloy with lead); Soldering (alloy with antimony, lead, tin)
Arsenic-based compound—White arsenic (arsenous oxide)	Calico printing; Glass; Insecticide/pesticide/germicide/fungicide; Mordant; Poison (for execution including old practices)
Arsenic-based compound—Lewisite (chloro-vinyl-dichlorarsine)	Chemical warfare
Arsenic-based compound—Calcium arsenate	Medical application; Preservation (timber, hide, leather); Weed killer
Arsenic-based compounds—Lead arsenate	Medical application; Preservation (timber, hide, leather)
Arsenic-based compound—Sodium arsenate	Preservation (timber, hide, leather)
Arsenopyrite	Metallurgy (arsenic)
Asbestos (actinolite)	Acid filtration; Asbestos cement; Bitumen; Brake/friction material; Insulation (thermal); Lagging (boilers, steam pipes); Paint filler (for special properties); Plastics (chemical resistant)
Asbestos (amosite)	Asbestos textile; Insulator (high temperature); Marine particle board; Paint filler (for special properties)
Asbestos (anthophyllite)	Acid filtration; Asbestos filter; Lagging (boilers, steam pipes); Paint filler (for special properties)
Asbestos (chrysotile)	Asbestos cement; Asbestos filter; Asbestos paper; Asphalt; Board/panel; Brake/friction material; Caulking; Ceramics (including fired tiles, composites, porcelain); Hydrogen sulphide manufacturing (*see* 'sulphur-based products'); Insulator (electrical); Insulator (sound); Jointing sheet; Packing; Plastics (filler); Roofing material; Sealing/lining; Vinyl sheet/linoleum/oil cloth; Vibration damping (along with lead); Vodka
Asbestos (crocidolite)	Asbestos cement; Asbestos textile; Gasket (acid resistant); Lagging (boilers, steam pipes); Packing (acid resistant); Paint filler (for special properties)
Asbestos (tremolite)	Asbestos cement; Bitumen; Brake/friction material; Insulation (thermal); Paint filler (for special properties); Plastics (chemical resistant)
Asphalt/bitumen/pitch/tar	Grease; Insulator (electrical); Metallurgy (iron); Preservation (electrical cables, metal, timber); Reductant; Road (paving, road making); Varnish

(continued)

Mineral/metals/rocks	Product/process
Asphaltic rock/natural bitumen (including tar sand)	Petroleum coke; Road metal (paving); Roofing material; Sulphur recovery
Attapulgite/fuller's earth	Adhesive; Bleaching; Catalyst; Cement grouting; Drilling (oil well); Explosion/explosive/pyrotechnics (including gun powder, dynamite); Insecticide carrier; Pharmaceuticals; Purification/refining/cleaning (edible oil); Purification/refining/cleaning (gases including natural gas); Sealing/lining
Aviation turbine fuel or ATF	Transportation (air)
Axinite	Gem (minor importance); Ornament/jewellery
Baddeleyite	Abrasive/grinding (wheel, paper, cloth); Ceramics (including fired tiles, composites, porcelain); Chemicals; Crucible; Dentistry; Electro-ceramics; Enamel; Fountain pen nib; Fuel cell (battery); Geological dating; Glass;
	Glazing; Insulator (electrical); Lacquer filler; Leather filler; Opacifier; Oxygen sensor; Paint filler; Refractory; Rubber (white) filler; Semiconductor; Zirconium metallurgy
Baddeleyite-based chemical—Zirconium carbonate	Pharmaceuticals
Baddeleyite-based chemical—Zirconium phosphate	Cosmetics (antiperspirants, ointments)
Ball clay	Animal/poultry feed; Ceramics (including fired tiles, composites, porcelain); Glazing (mixed with kaolin); Plastic (filler); Rubber (filler)
Barium	Degasification; Deoxidizer; Electronic equipment; Ferrite, Glass (photochromatic); Metallurgy (copper); Spark plug; Vacuum device (degassing)
Barium carbonate	Glass; Glaze; Enamel; Purification (phosphoric acid); Steel metallurgy
Barium chloride	Barium metallurgy; Brick making; Leather; Textile; Water treatment
Barium hydroxide	Ceramics; Lubricant; Organic compounds; Sugar; Vinyl sheet (PVC)
Barium nitrate	Detonator; Paint (primer); Signalling device
Barium oxide	Glass; Glaze
Barium peroxide	Desulphurization; Furnace; Hydrogen peroxide manufacture
Barytes	Adhesive; Barium metallurgy; Chemicals (carbonate, chloride, hydroxide, nitrate, oxide and peroxide of barium); Coal washing/beneficiation; Construction (concrete aggregate); Drilling (oil well); Explosive; Glass (ordinary); Nuclear reactor; Paint (filler); Paint (dye, lithopone, pigment); Paper; Rubber (synthetic); Toys; X-ray/radiology
Basalt	Agriculture; Brake/friction material; Horticulture; Hydroponics; Insulator (heat); Insulator (sound); Rock wool
Bastnasite	Metallurgy (rare earth metals)

(continued)

Mineral/metals/rocks	Product/process
Bauxite (includes activated, calcined, sintered and fused)	Abrasive/grinding (fused bauxite); Alumina (aluminium oxide); Aluminium hydroxide; Cement (ordinary portland, high- and low-iron alumina cement); Cordierite (artificial); Desiccation; Drilling (proppant in deep drilling); Emery (artificial); Cordierite (artificial); Metallurgy (aluminium, iron, steel); Refractory (calcined and sintered bauxite), Synthetic cryolite; Welding
Bauxite-based chemical—Alum (ammonium)	Cement; De-staining; Fire extinguishing; Leather; Odour control; Paint (filler for special properties); Paper; Pharmaceuticals; Plastics; Printing ink; Rubber; Textile; Waterproofing; Water treatment
Bauxite-based chemical—Aluminium carboxylate	Cosmetics; Drilling; Lubricant/grease; Pharmaceuticals; Textile; Waterproofing
Bauxite-based chemical—Aluminium chloride	Bleaching; Catalyst; Cosmetics; Perfumery; Petroleum refining; Pharmaceuticals; Polishing (metal); Preservation (vegetables, meat); Titanium dioxide; Water treatment; Wool
Bauxite-based chemical—Aluminium sulphate (ferric)	Cement; Fire extinguishing; Paint (filler for special properties); Pharmaceuticals; Plastics; Printing ink; Rubber; Textile; Waterproofing; Water treatment
Bauxite-based chemical—Sodium aluminate	Acrylic; Ceramics; Glass; Paint (filler for special properties); Paper; Water treatment
Bentonite	Abrasive wheel (binder); Animal/poultry feed (binding agent); Bonding; Ceramics (including fired tiles, composites, porcelain); Construction (for preventing fluid loss and caving of walls during excavation); Cosmetics (including talcum powder); Drilling (oil well); Emulsifier; Foundry (metal casting); Insecticide/fungicide (emulsifying agent); Iron metallurgy (pellets); Iron nugget; Naturopathy; Paint (emulsifying agent); Paint filler (for special properties); Paper (bonding agent); Pharmaceuticals; Polishing; Purification (sewerage water); Refining (edible oils and fats); Refractory (binder); Rubber (including synthetic rubber); Sealing/lining; Soaps/detergent/toilet powder; Vinyl sheet/linoleum/oil cloth (bonding agent); Viscosity enhancer; Welding rod (binder for coating)
Benzene	Antiknock additive; Hair dye; Soaps/detergent (synthetic detergent)
Beryl	Beryllium oxide
Beryllium	Aircraft (alloy); Alloys; Chemicals (*see below*); Neutron generation; Non-sparking tools (beryllium-copper alloy); Nuclear reactor (fuel element, moderator, heat-transfer unit); X-ray/radiology
Beryllium-based chemical—Beryllium acetate, bromide, carbonate, fluoride, hydroxide, nitrate, perchlorate	Analytical chemistry; Ceramics
Beryllium-based chemical—Zinc-beryllium silicate	Fluorescent light applications

(continued)

Mineral/metals/rocks	Product/process
Beryllium oxide (a derivative of beryl)	Ceramics; Metallurgy (beryllium)
Biotite (ground)	Paint (filler)
Bismite (bismuth ochre)	Metallurgy (bismuth)
Bismuth	EnviroBrass (lead-free brass); Lipowitz's metal (alloy with lead and tin), Newton's metal (alloy with lead and tin); Nuclear reactor (fuel, alloy with uranium); Polonium (radioactive material); Rose's metal (alloy with lead and tin, melts at 94 °C); Rust-proof coating (temporary, low-melting alloys washable with hot water); Safety fuse (fuse wire, alloy with cadmium, lead and tin); Safety plug (alloy with cadmium, indium and tin); Water sprinkler (automatic, alloy with cadmium, lead and tin, melts at 60 °C); Wood's metal (melts at 70 °C)
Bismuth compounds (hydroxide, nitrate, oxide, sub-carbonate, sub-chloride, sub-iodide, trichloride, trioxide etc.)	Ceramics (porcelain); Cosmetics; Glass; Pharmaceuticals; Superconductor
Bixbite	Gem
Bog iron ore	Metallurgy (iron); Purification/refining/cleaning (gases including coal gas)
Borax	Agriculture/horticulture; Analytical chemistry (borax-bead test); Artificial gem; Ceramics (including fired tiles, composites, porcelain); Cosmetics (including talcum powder); Edible salt; Electroplating (bath); Enamel; Fire proofing; Fire retardant; Glass (borosilicate glass); Glazing; Ink (indelible); Metallurgy (copper, chromium, cobalt, iron, nickel, uranium); Paper; Pyrotechnics (fireworks); Soldering; Textile; Tooth paste/powder; Vanaspati (butter-like fat of vegetable origin); Welding
Borax-based compound—Boric acid	Ferro-boron; Herbicide; Insecticide/fungicide/germicide; Medical application (as antiseptic and for fungal infection of horse); Metallic glass; Metallurgy (boron); Silicone (silli-putty)
Borax-based compound—Boric oxide	Boron carbide; Boron nitride; Ferro-boron; Metallic glass; Metallurgy (boron)
Borax-based compound—Sodium borate	Analytical chemistry (low voltage DNA analysis) Herbicide; Insecticide/fungicide/germicide
Borax-based compound—Sodium per borate	Herbicide; Insecticide/fungicide/germicide; Soaps/detergent/toilet powder
Borax-based compound—Sodium organo-borate (liquibor)	Hydraulic brake

(continued)

Mineral/metals/rocks	Product/process
Borax-based compound—Boron hydride	Rocket fuel
Borax-based compound—Lithium borate	Analytical chemistry (high voltage DNA analysis)
Borax-based compound—Magnesium diboride	Superconductor
Bornite	Metallurgy (copper)
Boro-gypsum (byproduct from boric acid manufacturing)	Cement
Boron	Aircraft (boron-containing metal-matrix composite); Ceramics (metal-matrix composite in combination with aluminium); Magnet (permanent, alloy with iron and neodymium), Optical fibre; Plant nutrient (micronutrient); Pyrotechnics (fireworks); Rocket fuel; Semiconductor; Space technology (space shuttle, boron-containing metal-matrix composite); Sports car
Boron-10 (isotope of boron)	Neutron detection; Nuclear reactor (moderator and shield)
Boron-11 (isotope of boron)	Nuclear reactor (fuel element, alloy with uranium)
Boron carbide	Diamond dressing; Die (for ceramic tools); Metallurgy (iron); Missile; Nuclear reactor (as shield); Precision tools; Ultra-hard material
Boron nitride (or borazon or wurtzite)	Ceramics (advanced structural ceramics); Ultra-hard material
Bowenite	Gem (minor importance); Ornament/jewellery
Brass	Pancha Dhatu (5-metal alloy)
Brick clay/brick earth	Common bricks
Brick shale	Common bricks
Cadmium	Bearings; Bonding (gold chain elements); Cell (rechargeable, high-precision); Electric cable; Electroplating/metal plating; Nuclear reactor; Safety fuse (fuse wire, alloy with bismuth, lead and tin); Safety plug (alloy with bismuth, indium and tin); Silverware; Television (camera, picture tube, screen); Water sprinkler (automatic, alloy with bismuth, lead, tin); Wood's metal (alloy with bismuth, lead and tin)
Cadmium-based compound—Cadmium halides	Photography
Cadmium-based compound—Cadmium phosphor	Television (picture tube)

(continued)

Mineral/metals/rocks	Product/process
Cadmium-based compound—Cadmium sulphide (cadmium yellow)	Enamel; Glass; Ink (printing); Leather; Paint (pigment and dye); Paper; Rubber (including synthetic rubber); Soap; Textile
Cadmium-based compound—Cadmium sulpho-selenide (cadmium red)	Enamel; Glass; Ink (printing); Leather; Paint (pigment and dye); Paper; Rubber (including synthetic rubber); Soap; Textile
Cadmium-based compound—Cadmium tungstate	X-ray/radiology
Calcite	Adhesive; Beryllium metallurgy; Chemicals; Cosmetics (including talcum powder); Electrode; Glass; Glazing; Paint extender/thinner; Rubber (including synthetic rubber); Synthetic/imitation marble; Textile; Water treatment
Calcite (dogtooth spar)	Decoration (including art work, artifact)
Calcite (Iceland spar)	Distance measurement; Nicol prism in polariscope; Optical instruments (including Quarter-wave plate)
Calcite (Mexican onyx)	Decoration (including art work, artifact)
Calcium	Cell (absorbed electrolyte battery); Degasification; Metallurgy (thorium, vanadium); Nuclear reactor (a film of CaO serves to protect beryllium against attack by liquid sodium in the heat-transfer unit); Pharmaceuticals; Vacuum device (for degasification)
Calcium carbide (lime-based product)	Carbide lamp (petromax); Fruit ripening; Welding
Calcium chloride	Electric arc furnace (EAF)
Calcium magnesium acetate	De-icing
Calcium silicate	Edible salt (free-flowing table salt)
Calcium tungstate	Fluorescent light applications
Calomel	*See* ‘mercury compounds’
Carbon black/oil black	Ink (printing); Paint (pigment and dye); Rubber (synthetic)
Carbon fibre	*See* ‘graphite (manufactured)’
Carlita	*See* ‘perlite (expanded and milled)/Carlita/Dicalite’
Carnotite	Metallurgy (uranium, vanadium)
Causticized lignite/ sodium lignite	Drilling (high temperature of over 200 °C)
Caustic soda	Paper manufacturing (soda process)
Cassiterite	Tin metallurgy
Celestite	Desulphurization; Drilling (oil); Metallurgy (steel, Strontium); Paint (pigment); Purification of caustic soda; carbonate; Strontium hydroxide; Strontium nitrate; Strontium oxalate; Strontium peroxide; Strontium titanate
Cerargyrite	Metallurgy (silver)
Ceresin	*See* ‘ozokerite/ceresin’

(continued)

Mineral/metals/rocks	Product/process
Cerium	*See* 'rare earth metals'
Cerium compounds	*See* 'rare earth metal compounds'
Cerium oxide (ceria)	*See* 'rare earth metal compounds'
Cesium (cesium-133)	Atomic clock (can measure up to 10^{-18} s); Catalyst; Night illumination device (long distance of up to 16 km); Photoelectric cell; Photography (infrared); Photometry; Radio; Signalling device (maritime); Sniperscope; Snooperscope; Standard reference for 'metre' (distance travelled by light in $3335640952 \times 10^{-18}$ s); Television (camera, screen); Vacuum device
Chalcocite	Metallurgy (copper)
Chalcopyrite	Metallurgy (copper)
Chalk	Adhesive; Rubber (including synthetic rubber); Writing chalk
Charge chrome	*See* 'ferrochrome'
Chromite	Chemicals; Chrome-plating; Ferro-chromes (charge chrome, exothermic ferrochrome, high-carbon, low-carbon, medium-carbon, silico-chrome); Foundry; Kanthal; Metallurgy (chromium); Refractory; Stellite
Chromite-based chemical—Barium chromate	Ceramics; Linoleum; Paint (pigment); Rubber
Chromite-based chemical—Chromic acid	Analytical chemistry (reagent); Anodizing; Chrome-plating; Oxidizing agent; Preservation (metal)
Chromite-based chemical—Chromic oxide	Chrome-green; Glass; Glazing; Linoleum; Metallurgy (chromium); Paint (pigment); Polishing
Chromite-based chemical—Chromium dioxide	Cassette tape (audio and video)
Chromite-based chemical—Chromium sulphate (basic)	Leather; Mineral Khaki; Paint (pigment)
Chromite-based chemical—Lead chromate	Chrome-red *See also* 'lead compounds'
Chromite-based chemical—Potash-chrome alum	Leather; Photography; Textile
Chromite-based chemical—Potassium dichromate	Adhesive; Etching; Explosion/explosive; Film processing; Ink (printing); Lithography; Matches; Perfumery; Photography;
Chromite-based chemical—Sodium chromate (hydrated)	Inhibitor; Preservation (metal)
Chromite-based chemical—Sodium dichromate	Bleaching (oils, fats, waxes); Drilling; Glass; Leather; Oxidizing agent; Preservation (wood); Textile

(continued)

Mineral/metals/rocks	Product/process
Chromite-based chemical—Zinc chromate	Ceramics; Linoleum; Paint (pigment); Rubber
Chromium	Marinel; Metallization/metal powder; Nimocast; Surgery/surgical material (in combination with cobalt, chromium and nickel)
Chrysoberyl (alexandrite)	Gem; Gemmotherapy; Ornament/jewellery
Chrysoberyl (cat's eye)	Gem; Gemmotherapy; Ornament/jewellery
Cinnabar	Metallurgy (mercury)
Citrine/false topaz	*See* 'quartz—gem variety'
Clay (common)	*See* 'pottery clay'
Clay (ordinary)	*See* 'pottery clay'
Coal	Activated carbon; Brick burning; Calcium carbide; Cement; Chemical derivatives (ammonia, aniline, anthracene oil, benzene, benzole, carbolic acid, creosote oil, cresols, naphtha, naphthalene, naphthalene oil, phenol, pitch, pyridine, toluene, xylene, xylenols); Chloro-fluoro carbon (CFC); Coal gas; Coke; Deoxidizer; Domestic heating; Foundry (metal casting); Industrial heating; Iron nuggets; Lime and its burning; Locomotive; Metallurgy (iron, lead, tin, zinc); Pig iron; Producer gas; Sialon (ceramics); Sinters; Sponge iron (directly reduced iron); Sulphur recovery; Synthetic petroleum; Thermal power generation; Water gas (blue water gas); Water gas (carbureted)
Coal-based product—Coal gas	Bunsen burner; Davy's lamp (used in underground coal mines)
Coal-based product—Coke	Deoxidizer; Ferrochrome; Ferromanganese; Iron/pig iron; Metallurgy (chromium, copper, iron, lead, nickel, steel, zinc); Phosphorus recovery; Silicomanganese; Spiegeleisen; Water gas
Coal-based product—Producer gas	Diesel generators (starting fuel); Industrial furnaces (initial firing)
Coal-based product—Water gas (blue water gas)	Welding (steel)
Coal-based product—Water gas (carbureted)	Welding (steel)
Coal bed methane	*See* 'methane'
Coal gas	*See* 'coal-based products'
Coal mine (abandoned) methane	*See* 'methane'
Coal mine (working) methane	*See* 'methane'
Coal mine ventilation air methane	*See* 'methane'

(continued)

Mineral/metals/rocks	Product/process
Cobalt (cobalt-59) and its alloys	Alnico (alloy of iron, cobalt, aluminium, nickel); Chemicals (*see below* 'cobalt cake/beta cake'); Cobalt-60; Cobalt soap (*see below*); Cutting/boring (as binder in tungsten carbide tools); Drilling; Fertilizer (plant micronutrients); Magnet (permanent magnet, in alloy with aluminium powder, iron and nickel or with cerium, praseodymium, samarium); Missile (in alloy with niobium and nickel); Space technology (rocket and spacecraft in alloy with niobium and nickel); Stellite; Surgery/surgical material (in combination with chromium and nickel); Synthetic petroleum (alloy with thorium)
Cobalt-60	Coal washing (gamma radiolytic process); Radiotherapy; Sterilization
Cobalt chemical—Cobalt acetate (cobalt purple)	Paint (pigment and dye)
Cobalt chemical—Cobalt aluminate (cobalt blue)	Paint (pigment and dye)
Cobalt chemical—Cobalt carbonate (cobalt red)	Paint (pigment and dye)
Cobalt chemical—Cobalt chloride (cobalt blue)	Moisture indicator; Mordant (dry cleaning); Paint (pigment and dye)
Cobalt chemical—Cobalt oxide (cobalt black)	Paint (pigment and dye)
Cobalt chemical—Cobalt soaps (naphthenate and carboxylate of cobalt)	Desiccation
Cobalt chemical—Cobalt sulphate (cobalt red)	Paint (pigment and dye)
Cobalt chemical—Cobalt titanate (turquoise green)	Paint (pigment and dye)
Cobalt chemical—Cobalt-zinc oxide (cobalt green)	Paint (pigment and dye)
Cobalt soap	*See* 'cobalt chemicals'
Coke	*See* 'coal-based product'
Colemanite (boron mineral)	Boric acid manufacturing; Glass (reinforcement fibre glass); Synthetic borax
Colloidal graphite	*See* 'graphite-based products'
Columbite (niobium-tantalum ore)	Niobium, Tantalum
Common clay	*See* 'pottery clay'

(continued)

Mineral/metals/rocks	Product/process
Constantan (copper-nickel alloy)	Rheostat; Thermocouple
Copper	Alloys; Artificial diamond manufacturing (copper cup for skull melting); Ashta Dhatu (8-metal alloy); Babbitt metal; Bell metal; Brass; Bronze; Chemicals; Coinage (alloy with nickel or silver); Communication (telecommunication); Constantan; Copper sulphate; Cupro-nickel; Damascene art; Dentistry (amalgam with silver, tin and mercury); Electrical appliances; Electrical transmission; Electric equipment (motor/generator/transformer); Electronic equipment; EnviroBrass (lead-free brass); German silver; Gun metal (admiralty bronze); Manganin; Marinel; Metallurgy (gold); Monel metal; Pancha Dhatu (5-metal alloy); Porous bronze; Refractory (in Romelt steel-smelting furnace); Ship (protection of under-sea parts); Spinoidal alloy; Type metal (alloy with antimony, lead and tin); Utensils; Zari (imitation)
Copper sulphate	Paint (pigment and dye)
Copperas	*See* 'pyrites—Copperas/Melanterite'
Coral	Gem; Gemmotherapy; Ornament/jewellery
Cordierite (artificial)	Ceramics; Cordierite saggars
Cordierite (iolite)	Gem; Gemmotherapy; Ornament/jewellery
Corundum (*see* 'ruby' and 'sapphire' for gem varieties)	Abrasive/grinding (wheel, paper, cloth); Cement (asbestos); Emery (artificial); Foundry (metal casting); Polishing; Refractory; Tooth paste
Croccoite	Paint (pigment and dye)
Crushed stone (assorted)	Brick (common and hollow); Construction (including aggregate, concrete, structural material); Decoration (including art work, artifact); Mosaic; Rip-rap; Roofing material; Sealing/lining; Varnish
Crushed stone (basalt)	Brick; Construction (including aggregate, concrete, structural material); Road metal/road aggregate
Crushed stone (diorite)	Brick
Crushed stone (dolerite)	Road metal/road aggregate
Crushed stone (granite)	Road metal/road aggregate (in auxiliary roads)
Crushed stone (granite sand)	*See* 'sand (granite)'
Crushed stone (limestone)	Road metal/road aggregate
Crushed stone (marble chips)	Terrazzo
Crushed stone (marble dust)	Board/panel; Brick; Ceramics (fired tile); Mosaic; Tile (unfired)
Crushed stone (marble flour)	Catalyst, Cement; De-icing; Fertilizer; Road material/road aggregate; Soil conditioner
Crushed stone (quartzite etc.)	Ballast (railway and ship)

(continued)

Mineral/metals/rocks	Product/process
Crushed stone (slate granule)	Roofing material
Crushed stone (slate powder)	Adhesive; Asphalt/bitumen; Brick; Fertilizer carrier; Gramophone record; Insecticide/pesticide/germicide/fungicide; Insulator (electrical); Lubricant/grease; Paint filler (for special properties); Plastics; Rubber (including synthetic rubber); Sealant; Tiles (acoustic); Varnish
Cryolite	Abrasive/grinding (wheel); Bonding; Enamel; Glass; Insecticide/pesticide/germicide/fungicide; Metallurgy (aluminium): Welding
Cymogene	*See* ‘petroleum ethers’
Danburite	Gem (minor importance); Ornament/jewellery
Depletalloy (or D-38)	*See* ‘uranium-238’
Depleted uranium (DU)	*See* ‘uranium-238’
Desulpho-gypsum/Flue gas desulphurization (FGD) gypsum/scrubber gypsum	Cement
Diabase	Mineral wool/rock wool
Diamond (gem)	Ayurvedic medicine (traditional Indian system); Electronic equipment; Gem; Gemmotherapy; Micro-processor chip; Ornament/jewellery; Laser (Raman laser); Robotics; Semiconductor; Skin care; Space technology (weather satellite); Spectrophotometer; Thermal dosimeter
Diamond (industrial and artificial/synthetic)	Abrasive/grinding (wheel); Ceramics (composites); Cutting/boring; Die (for wire drawing); Heat sink; Laser/maser; Record player; Surgical reamers
Diamond (micro/nano)	Electronic equipment (computer chip); Semiconductor
Diaspore	Ceramics (including fired tiles, composites, porcelain); Insecticide/pesticide/germicide/fungicide (carrier); Refractory (high alumina)
Diatomite	Abrasive (toothpaste, metal polish, scrub, soap); Agriculture/horticulture; Animal feed; Brake; Ceramics (including fired tiles, composites, porcelain); Climatology; Construction (including aggregate, concrete); Explosion/explosive (dynamite); Fertilizer; Filter/filtration; Glazing; Handling/storage (chemicals); Hydroponics; Insecticide/pesticide/germicide/fungicide; Insulator (heat); Insulator (sound); Matches; Medical application; Paint extender/thinner; Paint filler (flattening agent); Paper; Polishing; Purification/refining/cleaning (beer, edible oil, toxic liquid); Refractory; Rubber (including synthetic rubber); Sealing/lining; Soap; Sulphur recovery; Tooth paste/powder; Water glass/liquid glass (sodium silicate); Water treatment
Dicalite	*See* ‘perlite (expanded and milled)/Carlita/Dicalite’
Diesel (high speed or HSD)	Transportation (road)

(continued)

Mineral/metals/rocks	Product/process
Diesel oil (light or LDO)	Industrial machinery (tractors, concrete mixer etc.)
Dimension stone—Commercial granite (includes andesite, anorthosite, basalt, charnockite, diabase, diorite, dolerite, felsite, gabbro, gneiss, granite, khondalite, leptynite, monzonite, porphyry, pyroxenite, rhyolite, schist, syenite)	Architectural works (door frames, flooring tiles, monuments, roofing tiles, temples, tombstones, wall, wall tiles, window sills etc.); Art works (carvings, sculpturing, statuary); Ashlars; Engineering construction (beams, bridges, pavements etc.); Furniture (shelves, stools, table frames, table tops); Metrology; Petty decorative and consumer items (ashtrays, paper weights, pen stands); Sanitary ware (bathtubs, kitchen platforms, wash basins—all unfired)
Dimension stone—Commercial limestone (flaggy limestone or flagstone)	Architectural works (door frames, flooring tiles, monuments, roofing tiles, temples, tombstones, wall tiles, window sills etc.); Ashlars; Furniture (shelves, stools, table frames, table tops); Sanitary ware (bathtubs, kitchen platforms, wash basins—all unfired)
Dimension stone—Commercial marble (includes calcite, dolomite, marble, onyx marble, serpentine, travertine)	Architectural works (door frames, flooring tiles, monuments, roofing tiles, temples, tombstones, wall, wall tiles, window sills etc.); Art works (carvings, sculpturing, statuary); Ashlars; Furniture (shelves, stools, table frames, table tops); Petty decorative and consumer items (ashtrays, paper weights, pen stands); Sanitary ware (bathtubs, kitchen platforms, wash basins—all unfired)
Dimension stone—Commercial sandstone (includes sandstone, quartzite, fuchsite quartzite)	Architectural works (door frames, flooring tiles, monuments, roofing tiles, temples, tombstones, wall, wall tiles, window sills etc.); Ashlars; Furniture (shelves, stools, table frames, table tops); Petty decorative and consumer items (ashtrays, paper weights, pen stands); Sanitary ware (bathtubs, kitchen platforms, wash basins—all unfired)
Dimension stone—Commercial slate (includes phyllite, slate)	Architectural works (door frames, flooring tiles, monuments, roofing tiles, tombstones, wall, wall tiles, window sills etc.); Ashlars; Furniture (shelves, stools, table frames, table tops); Sanitary ware (bathtubs, kitchen platforms, wash basins—all unfired); Switch board; Writing slate
Diopside	Gem (minor importance); Ornament/jewellery
Dolomite	Adhesive; Cement; Ceramics (including fired tiles, composites, porcelain); Construction (aggregate, concrete); Ferromanganese; Fertilizer; Filter/filtration; Foundry; Glass; Pig iron; Leather; Lime and its burning; Metallurgy (iron, magnesium, manganese and steel); Opacifier; Paper; Pharmaceuticals; Refractory; Seawater magnesia; Silicomanganese; Spiegeleisen; Sponge iron (directly reduced iron); Underground coal mine; Water treatment (sewage water); Soil conditioning
Dysprosium	*See* 'rare earth metals'
Dunite	Iron metallurgy; Refractory; Soil conditioning
Emerald	Gem; Gemmotherapy; Ornament/jewellery; Skin care
Enstatite	Gem (minor importance); Ornament/jewellery
Epidote	Gem (minor importance); Ornament/jewellery

(continued)

Mineral/metals/rocks	Product/process
Ethylene/olefine	Alcohol (ethyl alcohol); Organic solvents; Polyester; Polyethylene; Radiator antifreeze; Resin (synthetic)/plastics; Rubber (synthetic rubber); Soaps/detergents/toilet powder (including synthetic detergent); Terylene; Vinyl sheet/linoleum/oil cloth (includes PVC)
Euclase	Gem (minor importance); Ornament/jewellery
Europium	*See* 'rare earth metals'
Exothermic ferrochrome	*See* 'ferrochrome'
Expanded/exfoliated graphite	*See* 'graphite-based products'
Feldspar	Abrasive/grinding (wheel); Anti-skid; Bone china; Cell (battery); Ceramics (including fired tiles, composites, porcelain); Coal washing; Dentistry; Enamel; Glass; Glazing; Metallurgy (steel); Paint extender/thinner; Plastics; Potash-manufacturing; Refractory; Welding
Feldspar (Amazonite)	Gem; Gemmotherapy; Ornament/jewellery
Feldspar (Moonstone)	Gem; Gemmotherapy; Ornament/jewellery
Feldspar (Sunstone)	Gem; Gemmotherapy; Ornament/jewellery
Ferrites (nickel-zinc ferrite, manganese-zinc ferrite, barium ferrite and strontium ferrite)	Automotive parts (wind screen wiper); Cassette; Electric equipment; Electronic equipment; Magnet (permanent); Microwave oven; Radio; Speaker; Telecommunication; Telephone; Television
Ferro-boron	Degasification; Deoxidizer; Metallurgy (iron)
Ferrocene (organic compound of iron)	Antiknock additive; Catalyst; Fireproofing; Photography
Ferrochrome (including charge chrome and high-, medium- and low-carbon ferrochrome)	Alloy steel; Metallurgy (steel); Stainless steel; Tool steel
Ferromanganese	Metallurgy (steel); Stainless steel manufacturing
Ferro-niobium	Stainless steel manufacturing
Ferrosilicon	Deoxidizer; Diamond dressing; Foundry; Electric equipment (transformer); Metallurgy (iron, steel)
Ferrovanadium	Metallurgy (steel)
Fireclay	Cordierite (artificial); Crucible (clay-bonded); Refractory; Sialon
Fluorite/fluorspar and 'green quartz'	Cement; Ceramics (including fired tiles, composites, porcelain); Chemicals; Enamel; Ferro-molybdenum; Fluorine gas; Gem; Glass (float, fibre and opalescent); Hydrofluoric acid; Metallurgy (iron, molybdenum and steel); Opacifier; Ornament/jewellery
Fluorite-based intermediate product—Aluminium fluoride	Ceramics; Enamel; Glass (optical); Metallurgy (aluminium); Opacifier

(continued)

Mineral/metals/rocks	Product/process
Fluorite-based intermediate product—Fluorine gas	Chemicals; Metallurgy (uranium); Tooth paste/powder; Water treatment (fluorination)
Fluorite-based intermediate product—Fluoro-boric acid	Electroplating/metal plating; Metallurgy (tin)
Fluorite-based intermediate product—Fluoro-silicic acid	Electroplating/metal plating; Synthetic cryolite; Water treatment (fluoridation)
Fluorite-based intermediate product—Hydrofluoric acid	Antiknock (high-octane petroleum); Etching (glass, semiconductor devices); Fluorine gas manufacturing; Fluoro-silicic acid; Metallurgy (niobium, tantalum); Potassium fluoride
Fluorite-based intermediate product—Potassium fluoride	Aromatic fluorides; Fluorine gas manufacturing; Metallurgy (niobium, tantalum); Pharmaceuticals
Fluorite-based intermediate product—Synthetic cryolite	Metallurgy (aluminium)
Fluorine-based compound—Chlorofluorocarbon (CFC)	Aerosol; Air-conditioning; Graphite purification; Refrigeration; Sterilization
Fluorine-based compound—Fluoro-carbon	Etching (semiconductor); Filter (fluoro-polymer filter); Semiconductor fabrication
Fluorine-based compound—Fluoro-silicates of ammonia, magnesium zinc	Preservation (timber, hide)
Fluorine-based compound—Hydrogen fluoride gas (anhydrous)	Chlorofluorocarbon (CFC) manufacturing; Metallurgy (uranium)
Fluorine-based compound—Sodium fluoride	Purification (fluorine gas); Tooth paste/powder
Fluorine-based compound—Sodium mono-fluoro-phosphate	Toothpaste/powder

(continued)

Mineral/metals/rocks	Product/process
Fluorine-based compound—Sodium fluoro-silicate/ hexa-fluoro-silicate/ silico-fluoride	Glass
Fluorine-based compound—Stannous fluoride	Tooth paste/powder
Fluorine-based compound—Uranium hexafluoride	Metallurgy (uranium)
Fluoro-gypsum (byproduct from hydrofluoric acid manufacturing)	Cement; Fertilizer
Forsterite	Refractory bricks (roofs in copper-smelting furnaces)
Frac sand	*See* 'quartz—industrial varieties, silica sand'
Franklinite	Metallurgy (zinc)
Fuchsite mica (powder)	Therapy (superstitious belief)
Fuchsite quartzite/ Greenlandite/Indian jade	Gem; Gemmotherapy; Ornament/jewellery
Fullerene	*See* 'graphite (manufactured)'
Furnace oil	Industrial heating (initial firing of furnace, engine etc.)
Fused quartz	Laser; Refractory; Thermometer (gallium, for measuring high temperature, 500–1,200 °C)
Gadolinite	Metallurgy (rare earth metal gadolinium)
Gadolinium	*See* 'rare earth metals'
Gadolinium compound	*See* 'rare earth metal compounds'
Galena	Metallurgy (lead)
Gallium (normal)	Aircraft (alloy); Artificial gem (gadolinium-gallium-garnet or GGG); Electronic equipment; Fire alarm; Optical mirror; Telephone (portable receiver); Thermometer (500–1,200 °C range)
Gallium-72 (isotope)	Radiotherapy
Gallium arsenide	Photovoltaic cell; Semiconductor; Space technology (satellite); Telecommunication; Transistor
Gallium halides	Catalyst
Gallium phosphoride	LCD display
Gallium compound—Organic salt	Pharmaceuticals
Gamet	*See* 'garnet—gamet'
Garnet	Anti-skid; Artificial gem (yttrium-aluminium-garnet or YAG which is a substitute of diamond, ruby and gadolinium-gallium-garnet or GGG); Laser (yttrium-aluminium-garnet or YAG); Polishing; Radar (yttrium-iron-garnet composite); Sparkplug cleaning; Sand blasting

(continued)

Mineral/metals/rocks	Product/process
Garnet-gamet	Gem; Ornament/jewellery
Garnet-gomed	Gem; Gemmotherapy; Ornament/jewellery
Germanium	Catalyst (coal hydrogenation); Electronic equipment; Hearing aid; Infrared optics; Lenses; Magnetic field measurement; Metallurgy (gold); Optical fibre; Pharmaceuticals; Rectifier; Television; Thermistor; Transistor
German silver (copper-nickel-zinc alloy)	Decoration (artifacts); Utensils (tableware, cutlery)
Glauconite	Water treatment (softening) after activating glauconite by sodium chloride solution
Goethite (minette)	Metallurgy (iron)
Gold (including nano-gold)	Ashta Dhatu (8-metal alloy); Ayurvedic medicine (traditional Indian system); Catalytic converter; Density (gold-indium alloy); Fibre glass (manufacturing machinery, alloy with gold or rhodium); Monetary reference standard; Ornament/jewellery; Rayon (manufacturing machinery, alloy with platinum); Water potability test; White gold; Zari
Gomed	*See* 'garnet—gomed'
Graphene	*See* 'graphite-based products'
Garnierite	Metallurgy (nickel)
Graphite	Adhesive (high-temperature application); Aircraft; Alloy (nonmetallic); Bearing; Brake/friction material; Carbon brushes (of electric motor/generator/transformer); Cell (battery); Colloidal graphite; Crucible; Drilling; Expanded/exfoliated graphite; Explosion/explosive; Foundry (metal casting); Fuel cell (battery); Fullerene; Graphene; Graphite/carbon fibre; Isostatic graphite mould; Laser; Lubricant/grease (high-temperature and high-pressure applications); Magnetic tape; Metallurgy (steel, for recarburization); Paint (pigment and dye); Pencil/crayon; Porous bronze; Pyrolytic graphite; Refractory; Sintered graphite; Synthetic graphite; White carbon
Graphite-based product—Colloidal graphite	EMI-shield
Graphite-based product—Expanded/exfoliated graphite	Packing (including gasket); Sealing/lining (high-performance applications like oil refineries, rockets, nuclear and thermal power plants etc.)
Graphite-based product—Graphene	Carbon nano-sheet; Electronic equipment (computer chip); Transistor
Graphite-based product—Isostatic graphite mould	Tools (for pressure sintering of high performance tools made of metals, ceramics and diamond)
Graphite-based product—Porous bronze	Light portable motors (used in business machines, domestic appliances, starters in automobiles)

(continued)

Mineral/metals/rocks	Product/process
Graphite-based product—Sintered graphite (with steel)	Gear (cogs)
Graphite/carbon fibre	*See* 'graphite (manufactured)'
Graphite (manufactured)	Aircraft; Carbon nano-balls; Carbon nano-tube; Solar cell (battery) panels; Space technology (including rocket, satellite, spacecraft); Sports car
Fullerene	
Graphite (manufactured)—Graphite/carbon fibre	Sealing/lining (high-temperature equipments, rocket nozzles); Sporting goods (golf club, tennis racket, fishing rod, sail boat)
Graphite (manufactured)—Pyrolytic graphite	Space technology (rocket nozzle cone); X-ray/radiology
Graphite (manufactured)—Synthetic graphite	Electrode; Nuclear reactor; Foundry; Steel metallurgy (recarburization)
Graphite (manufactured)—White carbon	Not yet known
Gypsum	Adhesive; Beet sugar; Board/panel; Brick (fly-ash); Cement; Construction (including aggregate, concrete, structural material); Cosmetics (powder); Decoration (artifact by casting); Dust suppression (including coal dust); Fertilizer; Foundry (metal casting); Imitation marble; Insecticide/pesticide/germicide/fungicide; Insulator (sound); Keene's plaster; Metallurgy (nickel, high grade lateritic ore); Paint (extender/thinner and filler); Paper; Pencil/crayon and writing chalk; Pharmaceuticals; Plaster/stucco/putty; Plaster of Paris (POP) mould (for potteries, rubber stamps, teeth etc.); Rubber (including synthetic rubber); Soil conditioning; Sulphuric acid; Surgery/surgical material; Textile; Tile (unfired)
Gypsum (alabaster)	Decoration (artifact sculpting); Sculpture; Statuary (by sculpting)
Gypsum (satinspar)	Ornament
Gypsum (selenite)	Microscope (plates)
Hafnium	Cutting/boring (additive in carbide tools); Nuclear reactor
Hambergite	Gem (minor importance); Ornament/jewellery
Heavy crude oil	*See* 'petroleum including heavy crude oil and oil shale'
Heavy fuel oil	Thermal power generation; Transportation (ocean)
Helium (includes the isotope helium-3)	Cryogenic fuel; Nuclear reactor (coolant); Oxygen/air liquefaction; Refrigerator (testing); Rocket fuel; Space technology (space shuttle); Thermonuclear reactor (including fusion power generation, hydrogen bomb); Welding
Hematite	Alloys of iron; Cassette (audio and video tape); Cement; Concrete; Cosmetics (rouge); Drilling; Ferrites; Ferrocene (organic compound); Glassy steel; Iron/pig iron; Iron carbide; Metallurgy (iron, molybdenum); Nitrided steels; Paint (pigment and dye); Pellets; Preservation (metal); Sinters; Sponge iron (directly reduced iron); Welding (rod coating)
Hemimorphite	Metallurgy (zinc)

(continued)

Mineral/metals/rocks	Product/process
Hydraulic fracturing sand	*See* 'quartz—industrial varieties, silica sand'
Idiocrase	Gem (minor importance); Ornament/jewellery
Ilmenite	Metallurgy (titanium); Synthetic rutile (titanium dioxide)
Indium	Bearing (alloys with cadmium, copper, lead, copper); Brazing; Chemicals, Cinema (screen); Dentistry (alloy with gold); Die (for wire drawing); Electroplating/metal plating; Fluorescent light applications; Gasket; Optical mirror; Safety plug (alloy with bismuth, cadmium and tin); Sealing/lining; Soldering
Indium antimonide	Laser; Optical fibre; Semiconductor
Indium arsenide	Laser; Optical fibre; Semiconductor
Indium oxide	Fluorescent light applications; Infrared optics
Indium phosphide	Laser; Microprocessor chip; Optical fibre; Semi-conductor
Indium sesquioxide	Glass (coloured)
Indium sulphide	Fluorescent light applications; Infrared optics
Iolite	*See* 'cordierite'
Iridium (platinum group of metals)	Dentistry (alloyed with platinum, palladium); Gold fabrication; Standard references for kilogram and metre (alloy with 90 % platinum); Spark plug; Surgery/surgical material (alloyed with palladium, platinum); Thermocouple (alloy with rhenium)
Iron/pig iron and its alloys	Alnico (alloy of iron with aluminium, nickel, cobalt); Ashta Dhatu (8-metal alloy); Cast iron; Cupro-nickel; Ferro-silicon; Foundry (metal casting); Iron carbonyl; Iron powder; Magnet (low-temperature permanent magnet as alloy with boron and neodymium and ordinary magnet); Marinel; Metallization/metal powder; Metallurgy (steel); Monel metal; Mu-metal or permalloy (alloy of nickel and iron with copper, molybdenum); Pancha Dhatu (5-metal alloy); Prussian blue (Turnbull's blue); Radar (garnet-iron-yttrium composite); Steel; Wrought iron
Iron carbonyl	Iron powder manufacturing
Iron nugget (nodule)	Steel
Iron powder	Automotive parts; Electric equipment; Magnet (permanent)
Isostatic graphite	*See* 'graphite-based products'
Jadeite/jade	Gem; Gemmotherapy; Ornament/jewellery
Jasper	Touchstone for gold
Kaolin (china clay)	Adhesive; Bone china; Cassette; Catalyst; Cement (white); Ceramics (including fired tiles, composites, porcelain), Crayons; Cosmetics (including talcum powder); Explosion/explosive/pyrotechnics (including gun powder, dynamite); Glass; Glazing; Ink; Insecticide/pesticide/germicide/fungicide; Insulator (electrical); Iron/pig iron; Matches; Metakaolin; Paint extender/thinner; Paper; Pharmaceuticals; Pigment and dye (including ultramarine); Plaster/stucco/putty; Plastics; Pyrotechnics (fireworks); Refractory; Rubber (including synthetic rubber); Sealing/lining; Soaps/detergent/toilet powder; Synthetic zeolite; Textile; Tooth paste/powder
Kerosene	Domestic heating; Lamp (household)
Kimberlite	Cement; Synthetic zeolite

(continued)

Mineral/metals/rocks	Product/process
Kyanite	Gem; Gemmotherapy; Glass; Ornament/jewellery; Refractory
Lanthanum	*See* 'rare earth metals'
Lanthanum compound	*See* 'rare earth metal compounds'
Lanthanum oxide	*See* 'rare earth metal compounds'
Lasca	*See* 'quartz—industrial varieties'
Lazurite (lapis lazuli)	Gem; Gemmotherapy; Ornament/jewellery
Lead	Acid tank; Aircraft (for radiation shielding); Ashta Dhatu (8-metal alloy); Bearing (alloys with aluminium, copper, tin etc.); Brass; Bronze; Bullet/shot/shell; Cable sheath (for high-frequency telephone, television, radar signals); Cell/battery (storage type, lead and its alloys with antimony, calcium, tin); Chemicals; Glass (special); Lead glass; Lead soap (*see below*); Lenses; Lipowitz's metal (alloy with bismuth and tin); Newton's metal (alloy with bismuth and tin); Nuclear reactor (for radiation shielding); Pancha Dhatu (5-metal alloy); Pewter (alloy with antimony and tin); Plumbing; Printing type metal (alloy with antimony, copper and tin); Rose's metal (alloy with bismuth and tin); Safety fuse (alloy with bismuth, cadmium and tin); Soldering (alloy with lead); Sugar of lead (*see below*); Terne plating (for roofing sheet); Tetraethyl lead (based on lead-sodium alloy); Tube (collapsible, alloy with antimony and tin); Vibration damping (along with asbestos); White metal (alloy with antimony); Wood's metal; X-ray/radiology (radiation shielding)
Lead compound—Blue lead ($PbSO_4 \cdot PbO$)	Paint (pigment and dye)
Lead acetate (sugar of lead)	Desiccation (oil)
Lead arsenate	Insecticide/pesticide/germicide/fungicide
Lead chromates	Paint (pigment and dye)
Lead dioxide (PbO_2)	Adhesive; Glass; Glazing; Metallurgy (beryllium); Rubber (synthetic)
Lead hydroxide	Desiccation (oil)
Lead molybdate	Glazing; Paint (pigment and dye)
Lead mono-oxide (PbO)	Adhesive; Glass; Glaze; Rubber (synthetic)
Lead compound—Red lead (Pb_3O_4)	Adhesive; Glass; Glaze; Paint (pigment and dye); Rubber (synthetic)
Lead compound—White lead [$2PbCO_3.Pb(OH)_2$]	Lead soap (*see above*); Paint (pigment and dye)
Lead glass	Lenses; X-ray/radiology
Lead soap	Desiccation (oil)
Leco (lignite-based product)	Domestic heating (including cooking)
Lepidolite (lithium mineral)	Glass; Metallurgy (lithium, rubidium)

(continued)

Mineral/metals/rocks	Product/process
Lewisite	*See* 'arsenic-based compounds'
Lignite	Animal/poultry feed (pig feed); Bio-fertilizer; Causticized lignite/sodium lignite; Chemical derivatives (ammonia, aniline, anthracene oil, benzene, benzole, carbolic acid, creosote oil, cresols, naphtha, naphthalene, naphthalene oil, phenol, pitch, pyridine, toluene, xylene, xylenols); Domestic heating; Industrial heating (including fuel); Leco; Metallurgy (iron); Met-coke; Reductant; Thermal power generation
Lime (or quicklime or fat lime)	Calcium carbide; Chewing with betel leaves; Limelight; Milk-of-lime; Mineral wool (lime and slag wools); Paint (pigment and dye); Pharmaceuticals; Precipitated calcium carbonate (PCC); Preservation (food, fruits, vegetables); Slaked lime; Soil conditioning; Water treatment (sewage water)
Lime-based intermediate product (milk-of-lime)	*See* 'milk-of-lime'
Lime-based product (precipitated calcium carbonate or PCC)	*See* 'precipitated calcium carbonate (PCC)'
Lime-based intermediate product (slaked lime)	*See* 'slaked lime'
Lime-based intermediate product (milk-of-lime)	*See* 'milk-of-lime'
Limestone (including lime shell, kankar)	Adhesive; Calcium chloride; Caustic soda; Cement; Desulphurization; Ferromanganese; Fertilizer; Glass; Glazing; Hydraulic/natural cement; Insecticide/pesticide/germicide/fungicide (carrier); Lime (or quicklime) manufacturing; Metallurgy (calcium, iron, magnesium, steel); Pellets; Pencil/crayon and writing chalk; Polishing; Putty; Rubber (including synthetic rubber); Seawater magnesia; Silicomanganese; Sinters; Soda ash (soda); Sodium bicarbonate; Spiegeleisen
Limonite (brown iron ore)	Metallurgy (iron)
Liquefied natural gas (LNG)	Oxygen/air liquefaction
Liquefied petroleum gas (LPG)	*See* 'petroleum gas'
Liquid glass	*See* 'water glass/liquid glass/sodium silicate'
Lithium	Cell (battery); Bronze; Chemicals; Degasification; Glass (photochromatic); Metallurgy (copper); Space technology; Weldite
Lithium bromide	Air conditioner; Desiccation
Lithium carbonate	Ceramics; Pharmaceuticals
Lithium chloride	Air conditioner; Brazing; Desiccation; Welding
Lithium citrate	Pharmaceuticals
Lithium deuteride	Thermonuclear bomb (hydrogen bomb)

(continued)

Mineral/metals/rocks	Product/process
Lithium fluoride	Brazing; Welding
Lithium hydride	Balloon
Lithium hydroxide	Cell (rechargeable); Lithium stearate (metallic soap)
Lithium niobate	Electro-optical modulator
Lithium perchlorate	Rocket fuel
Lithium stearate (metallic soap)	Lubricant
Lonsdaleite	Ultra-hard material
Lubricating oil (petroleum refinery product, heavy end)	Electrical equipment (transformer, switchgear etc.); Lubricant/grease
Lutetium-177	*See* 'rare earth metals'
Magnesite	Caustic magnesia; Electrode (coating); Edible salt (free-flowing table salt, old use); Epsom salt; Forsterite manufacture; Magnesium sulphate (anhydrous); Pharmaceuticals (Epsom salt); Rubber (synthetic rubber)
Magnesite-based intermediate product—Caustic magnesia	Abrasive/grinding (wheel, paper, cloth); Agriculture/horticulture (protection against acid rain); Animal/poultry feed; Boiler/steam pipes; Catalyst; Cement; Dead-burnt magnesia (DBM) manufacturing; Enamel; Fertilizer (plant micronutrient); Filter/filtration; Glass; Glazing; Magnesium chloride manufacturing; Magnesium metal; Paper; Purification (edible oil); Rubber (synthetic rubber); Water treatment; Welding (ceramic)
Magnesite-based intermediate product—Dead-burnt magnesia	Fused magnesia; Refractory
Magnesite-based intermediate product—Fused magnesia	Refractory
Magnesite-based intermediate product—Light magnesia	Cosmetics
Magnesite-based intermediate product—Magnesium bromide	Cell (battery)
Magnesite-based intermediate product—Magnesium chloride	Deicing; Dust suppression; Magnesium metal
Magnesite-based intermediate product—Magnesium diboride	Superconductor

(continued)

Mineral/metals/rocks	Product/process
Magnesite-based intermediate product—Magnesium perchlorate	Cell (battery)
Magnesite-based intermediate product—Magnesium sulphate	Desiccation; Diet coke; Soil conditioning
Magnesite-based intermediate product—Magnesium tungstate	Fluorescent light applications
Magnesite-based intermediate product—Magnesium-zirconium orthotitanate	Condenser (electrical); Insulator (electrical); Radio
Magnesium and its alloys	Aircraft; Automotive parts (wheels); Cell/battery; Ceramics (composites); Degasification; Deoxidizer; Die casting; Electroplating/metal plating; Foundry (metal casting); Hydrogen fuel system; Metallization/metal powder; Metallurgy (boron, thorium, titanium); Missile (parts); Nuclear reactor (fuel element); Photographic flashlight; Pyrotechnics (fireworks); Quaternary casting alloy (90 % Mg); Radio (valve); Sand casting; Signalling device; Surgery/surgical material (biodegradable stent); Ternary casting alloy (93–97 % Mg); Textile (machines); Vacuum device
Magnetite (including nano-crystals)	Coal washing/beneficiation; Emery (artificial); Iron nugget (nodule); Metallurgy (iron); Pellet; Water purification (arsenic removal)
Malachite (kidney stone)	Gem; Gemmotherapy; Ornament/jewellery
Manganese	Alloys (nonferrous metals); Cupro-nickel; Deoxidizer; Desulphurization; Marinel, Metallization/metal powder; Metallurgy (steel); Stellite
Manganin (alloy of copper, manganese and only 2 % nickel)	Electrical equipment
Manufactured graphite	*See* 'graphite (manufactured)'
Marble chips	*See* 'crushed stone (marble chips)'
Marble dust	*See* 'crushed stone (marble dust)'
Marble flour	*See* 'crushed stone (marble flour)'
Marine gypsum (byproduct from recovery of common salt from seawater)	Cement
Melanterite	*See* 'pyrites—Copperas/Melanterite'

(continued)

Mineral/metals/rocks	Product/process
Mercury (quick silver)	Barometer; Calomel (*see below*); Catalyst (amalgam with rubidium); Dentistry (amalgam with silver, tin and copper); Mercury vapour boiler (for power generation); Mercury vapour lamp; Mercury switch; Metallurgy (gold, silver); Plastics; Rectifier; Thermometer (for measuring temperature up to 300 °C)
Mercury compound—Mercuric chloride	Insecticide/pesticide/germicide/fungicide; Medical application
Mercury compound—Mercuric oxide	Cell (dry); Paint (pigment and dye); Preservation of metal (ship bodies)
Mercury compound—Mercurous chloride (calomel)	Pharmaceuticals
Mercury cyanate (mercury fulminate)	Detonator
Mercury sulphide	Ink (printing); Paint (pigment and dye)
Mesothorium	Paint (luminescent paint); Radiotherapy
Metallic glass (special type of ferro-boron)	Electrical transmission; Electric equipment (trans former)
Met coke (lignite-based product)	Cement; Industrial heating (fuel); Metallurgy (iron)
Methane (including methane recovered from abandoned and working mines, coal bed, coal mine ventilation air and methane hydrate)	Domestic heating; Fertilizer; Industrial heating; Methanol; Thermal power generation; Transportation fuel
Methanol (methane-based product)	Antifreeze; Denaturing agent (alcohol, nuclear fuel etc.); Fuel cell
Methyl cyclo-pentadienyl manganese carbonyl	Calico printing; Leather; Matches; Photography
Milk-of-lime (lime-based intermediate product)	Caustic soda manufacturing; Sugar
Mineral jelly/petroleum jelly/Vaseline (petroleum refinery product)	Cosmetics; Explosion/explosive; Pharmaceuticals; Polishing
Mischmetall (intermediate product of mixed rare earths obtained during metallurgy)	*See* ‘rare earth metals’
Molybdenite	Metallurgy (molybdenum, rhenium)

(continued)

Mineral/metals/rocks	Product/process
Molybdenum	Analytical chemistry (nitrogen-fixing enzymes called 'nitrogenase'); Chemicals (*see below* 'molybdenum-99'), Electric bulb; Electronic equipment; Ferromolybdenum; Mercury switch; Metallization/metal powder; Radio (valve); Semiconductor (base); Stellite; Surgery/surgical material (in combination with cobalt, chromium and nickel)
Molybdenum-99	Radiotherapy
Molybdenum-based chemical—Ammonium molybdate	Analytical chemistry (reagent for determination of phosphorus)
Molybdenum disilicide	Ceramics
Molybdenum disulphide	Aerosol; Bearing (nylon); Electric appliances; Lubricant/grease
Molybdenum oxide	Catalyst (in industrial oxidation)
Monazite	Incandescent mantle; Metallurgy (mesothorium; rare earth metals, thorium)
Monel metal (mainly nickel-copper-iron alloy)	Aircraft; Electric equipment; Food can; Roofing material; Ship (components)
Moonstone	*See* 'Feldspar (moonstone)'
Morganite (vorobyevite)	Gem
Motor fuel or Mo-gas	Transportation (road)
Mu-metal or permalloy (alloy of nickel, iron, copper, molybdenum)	Magnetic shield
Muscovite mica—Block/film/sheet mica	Aircraft; Boiler/steam pipes; Capacitor; Compass; Electrical appliances; Electric motor/generator/transformer; Electronic equipment (computer washer); Furnace/oven, Geiger counter; Insulator (electrical); Laser (helium-neon); Microscope (polarizing); Microwave transmitter; Missile; Optical instruments; Oxygen-breathing equipment; Petromax; Radar; Radiation pyrometer; Radio; Refinery; Silvered mica; Submarine; Television; Thermal power plant; Thermal regulator; Window
Muscovite mica—Splittings	Micanite
Muscovite mica—Scrap mica	Glass-bonded mica; Reconstituted mica
Muscovite mica—Ground mica (including micronized mica)	Aluminium-mica alloy; Board (for fire protection); Cement (for wall-board joint); Cosmetics; Decoration (Christmas tree snow); Drilling (proppant); Foundry (metal casting); Insecticide/pesticide/germicide/fungicide; Insulation brick; Lubricant/grease; Nickel-coated mica; Paint (filler, pigment and dye); Plaster; Plastics; Roofing material; Rubber (including synthetic rubber); Sealing/lining; Stucco; Thermoplastics/thermoset; Wall paper; Welding (rod coating)

(continued)

Mineral/metals/rocks	Product/process
Muscovite-based intermediate product—Aluminium-mica alloy	Lubricant (solid and dry)
Muscovite-based intermediate product—Glass-bonded mica (micalex)	Insulator (electrical)
Muscovite-based intermediate product—Micanite	Board/panel; Paper; Electric motor/generator/trans-former
Muscovite-based intermediate product—Nickel-coated mica	Computer (cabinet); EMI-shield; Microprocessor chip
Muscovite-based intermediate product—Reconstituted mica	Mica paper
Muscovite-based intermediate product—Silvered mica	Electrical transmission circuit; Oscillator
Nahcolite	Beverage; Cosmetics (beauty application); Filter/filtration; Odour control; Pollution control (electrostatic precipitator)
Naphtha (petroleum derivative, light distillate)	Fertilizer (ammonium sulphate)
Naphthalene (petroleum derivative, slightly unsaturated)	Disinfectant; Moth balls (as fumigant)
Natural gas (includes compressed natural gas or CNG)	Carbon black, Cement manufacturing; Deoxidizer; Domestic heating; Ethylene; Fuel cell; Helium recovery; Industrial heating; Iron/pig iron; Liquefied natural gas (LNG); Liquefied petroleum gas (LPG); Metallurgy (iron, tungsten); Methane; Motor fuel (or Mo-gas or gasoline); Petroleum recovery (secondary); Propylene; Solvent (alcohol); Sponge iron (directly reduced iron); Sulphur recovery; Synthetic petroleum; Thermal power generation; Transportation fuel (road)
Neodymium	*See* ‘rare earth metals’
Neodymium compound	*See* ‘rare earth metal compounds’
Neodymium oxide	*See* ‘rare earth metal compounds’
Nepheline syenite	Glazing
Nephrite	Gem; Ornament/jewellery
Niccolite (naturally occurring mineral)	*See* ‘nickel arsenide (nickel-based chemical)’

(continued)

Mineral/metals/rocks	Product/process
Nickel and its alloys	Alnico (alloy of nickel and iron with aluminium, cobalt); Bronze; Catalyst; Cell/battery (rechargeable, in alloy with cadmium and in nickel-hydride form); Chemicals (*see below*); Coinage (in combination with copper); Constantan (copper-nickel alloy); Cupro-nickel; Cutting/boring (tools); Drilling (bits); Electronic equipment; Electroplating/metal plating; German silver (copper-zinc-nickel alloy); Hydrogenation; Manganin; Marinel; Missile (alloy with niobium and cobalt); Monel metal (alloy of mainly nickel and copper); Mu-metal or permalloy (alloy of nickel with iron, copper, molybdenum); Nimocast (alloy of mainly nickel and chromium); Nitinol (nickel-titanium alloy); Purification/refining/cleaning (petroleum, gases including coal gas); Robotics; Silver plate (silver and nickel); Smart wire; Space technology (rocket and spacecraft in alloy with niobium and cobalt); Spinoidal alloy; Stainless steel (in combination with chromium); Stellite; Superconductor; Surgery/surgical material (in combination with cobalt, chromium and molybdenum); White gold
Nickel arsenide	Glass (coloured)
Nickel oxide	Ceramics (coloured); Ferrite (in combination with hematite)
Nickel oxyhydroxide	Cell/battery
Nickel sulphate	Electroplating/metal plating
Niobium	Catalyst; Ferro-niobium; Marinel; Missile (in alloy with cobalt and nickel); Nuclear reactor (fuel element); Sodium lamp; Space technology (rocket and spacecraft, in alloy with cobalt and nickel); Superconductor (alloy with tin, titanium); Surgery/surgical material (powder); Vacuum device
Niobium carbide	Tungsten carbide
Niobium pentoxide	Ceramics; Glass (optical); Transducer
Nitinol	Surgery/surgical material (orthopedics)
Ochre	Paint (pigment and dye); Polishing (glass)
Oil shale—Petroleum (crude shale oil)	*See* 'petroleum including heavy crude oil and oil shale'
Olefine	*See* 'ethylene/olefine'
Onyx	*See* 'quartz—gem variety'
Opal	Gem; Gemmotherapy; Ornament/jewellery
Ordinary clay	*See* 'pottery clay'
Orpiment (natural arsenic trisulphide)	Hair remover; Paint (pigment and dye)
Osmium (platinum group of metals)	Compass; Fountain pen nib; Watch
Ozokerite/ceresin (natural mineral wax)	Art work (model making); Candle

(continued)

Mineral/metals/rocks	Product/process
Palladium (platinum group of metals)	Catalytic converter; Dentistry (alloyed with iridium, platinum); Electrical equipment; Electroplating/metal plating (plastic surfaces); Hydrogenation; Magneto; Ornament/jewellery; Purification/refining/cleaning (petroleum); Spark plug (heavy duty); Standard reference for kilogram; Surgery/surgical material (alloyed with iridium, platinum); Telephone; Thermocouple (alloy with rhenium); Watch; White gold
Patronite	Metallurgy (vanadium)
Pellets	Pig iron
Pearl	Gem; Gemmotherapy; Ornament/jewellery; Skin care
Peat	Bio-fertilizer; Brick (common) burning; Desiccation; Lime (or quick lime or fat lime) burning; Preservation (food, fruits, vegetables); Roofing material (cardboard felt); Scotch whisky; Soil conditioning; Surgery/surgical material (dressing)
Pentane	*See* 'petroleum ethers'
Pentlandite	Metallurgy (nickel)
Peridot (olivine)	Gem; Gemmotherapy; Ornament/jewellery
Peridotite	Carbon sequestration; Iron metallurgy
Perlite (natural)	Expanded perlite; Foundry (metal casting); Slag granulation
Perlite (expanded and milled)/Carlita/Dicalite	Boiler/steam pipes; Ceramics (including fired tiles, composites, porcelain); Construction (aggregate, concrete); Fertilizer (carrier); Fertilizer (plant micro-nutrient); Filter/filtration; Foundry; Handling/storage (cryogenic chemicals); Herbicide; Horticulture; Hydroponics; Ice box; Insecticide/pesticide/germicide/fungicide; Insulator (heat); Insulator (sound); Paint (extender/thinner); Plaster; Plastics; Polishing; Pollution control; Purification/cleaning (toxic liquid); Refractory; Soap
Perlite (expanded granules)	Drilling; Nuclear reactor
Petalite (lithium mineral)	Ceramics; Glass; Glazing; Metallurgy (lithium)
Petroleum coke (petroleum refinery product, heavy end)	Electrode (power-intensive metallurgical process)
Petroleum (crude/natural)	Bonding (mortar, old usage); Construction (old usage); Lamp (household, old usage); Transportation fuel (road, rarely)
Petroleum ethers (petroleum refinery product, light distillate)—Cymogene	Ice manufacturing
Petroleum ethers (petroleum refinery product, light distillate)—Pentane	Photometry; Standard reference for measuring illuminating power
Petroleum gas (including liquefied petroleum gas or LPG)	Annealing; Carburization; Cutting (metal); Domestic heating (including cooking)

(continued)

Mineral/metals/rocks	Product/process
Petroleum including heavy crude oil and oil shale (refinery products)	Asphalt/bitumen/pitch/tar (heavy end); Aviation turbine fuel or ATF (middle distillate); Benzene (aromatic derivative); Carbon black/oil black; Diesel (high speed or HSD, middle distillate); Diesel oil (light or LDO, middle distillate); Ethylene/olefine; Fuel cell; Furnace fuel oil (heavy end); Heavy fuel oil (heavy end); Kerosene (middle distillate); Lubricating oil (heavy non-fuel end); Mineral jelly/ petroleum jelly/Vaseline; Motor fuel or Mo-gas or gasoline (light distillate); Naphtha (light distillate); Naphthalene (aromatic derivative); Petroleum coke (refinery product, heavy end); Petroleum ethers (light distillate); Petroleum gas (refinery product, light distillate); Propylene; Sulphur recovery; Toluene (aromatic derivative); Wax/paraffin; White oil; White spirit; Xylene (aromatic derivative)
Phenacite	Gem (minor importance); Ornament/jewellery
Phlogopite mica	Aircraft (spark plug); Electrical appliances (heating element); Paint (pigment and dye); Searchlight; Thermoplastics/thermoset
Phosphogypsum (byproduct from phosphoric acid manufacturing)	Cement; Fertilizer
Phosphor (fluorescent substance)	Fluorescent light applications (substance for coating the surface)
Phosphoric acid	Beverage (soda); Fuel cell
Phosphoric acid-based products—Di-sodium phosphate	Food processing; Tooth paste; Water treatment
Phosphoric acid-based products—Sodium ammonium hydrogen phosphate	Analytical chemistry; Sodium hexa-meta phosphate (calgon) preparation
Phosphoric acid-based products—Sodium hexa-meta phosphate (calgon)	Boiler/pipes
Phosphoric acid-based products—Sodium mono-phosphate	Food processing; Tooth paste; Water treatment
Phosphoric acid-based products—Sodium pyrophosphate	Food processing; Tooth paste; Water treatment
Phosphoric acid-based products—Sodium tri-poly-phosphate	Detergent; Food processing; Tooth paste; Water treatment
Phosphoric acid-based products—Tetra-sodium phosphate	Food processing; Tooth paste; Water treatment
Phosphoric acid-based products—Tri-sodium pyrophosphate	Food processing; Tooth paste; Water treatment

(continued)

Mineral/metals/rocks	Product/process
Phosphorite	Animal/poultry feed; Bone china; Fertilizer; Glass; Glazing; Lamp (household); Phosphogypsum (byproduct from phosphoric acid manufacturing); Phosphoric acid; Phosphorus recovery; Preservation (metal); Soaps/detergent/toilet powder; Soil conditioner; Sodium lamp
Phosphorus (red)	Alloy (nonmetallic); Bronze; Cap-gun caps; Chemicals; Matches; Pharmaceuticals; Saccharin; Semiconductor; Vitamins
Phosphorus (yellow)	Alloy (nonmetallic); Ammunition/bombs; Bronze; Chemicals; Deoxidizer; Fluorescent light applications; Herbicide (glysophate); Pharmaceuticals: Phosphor (fluorescent substance); Saccharin; Semiconductor; Vermicide; Vitamins
Phosphorus-32	Pharmaceuticals (radiopharmaceuticals or radio-nuclide); Radiotherapy
Piedmontite	Gem (minor importance); Ornament/jewellery
Pipe clay	Smoking pipe
Pitchblende	Metallurgy (uranium)
Platinum (platinum group of metals)	Analytical chemistry; Catalyst; Catalytic converter; Crucible; cutting/boring; Dentistry (alloyed with iridium, palladium); Electrical equipment; Electrode boring; Fibre glass (manufacturing machinery, alloy with gold or rhodium); Furnace/oven; Magneto; Ornament/jewellery; Rayon (manufacturing machinery, alloy with gold or rhodium); Space technology (spacecraft); Spark plug (heavy duty); Standard references for kilogram and metre (alloy with 10 % iridium); Surgery/surgical material (alloyed with iridium, palladium); Telephone; Thermocouple (alloy with rhenium)
Plutonium-239	Fission bomb/atom bomb; Nuclear reactor (fast breeder); Weaponry (nuclear)
Plutonium carbide	Nuclear reactor (fast breeder)
Polonium (bismuth-based material)	Poison (for execution and murder); Space technology (satellite, lunar vehicle (fuel)); Static electricity (control device)
Potash—Caustic potash (potassium hydroxide)	Catalyst; Cell; Chemicals (aluminate, boro-hydrate, bromate, bromide, carbonate, cyanide, fluorosilicate, formate, gluconate, laurate, manganate, oleate, phosphate and titanate of potassium); Electroplating; Grease; Herbicide; Pharmaceuticals; Soaps/detergents
Potash—Potassium carbonate	Chemicals (acetate, bicarbonate, bi-sulphite, ferro-cyanide, fluoride, meta-silicate etc.); Desiccation; Electroplating; Enamel; Fire extinguishing; Food processing; Glass; Paint (pigment and dye); Pollution control (extraction of carbon dioxide from industrial gas); Soaps; Television; Textile
Potash—Potassium chloride	Caustic potash manufacturing; Fertilizer; Soil conditioning
Potash—Potassium fluoride	Metallurgy (potassium); Pharmaceuticals
Potash—Potassium phosphate	Adhesive; Anti-freeze agent; Casein (soluble milk protein); Detergent (industrial); Fertilizer (liquid); Paint (filler); Plastics; Water treatment

(continued)

Mineral/metals/rocks	Product/process
Potash—Potassium schoenite (hydrate of potassium-magnesium sulphate)	Fertilizer; Soil conditioner
Potash—Potassium silicate/metasilicate	Cathode ray tube; Preservation (paint); Television; Welding (rod coating)
Potash—Potassium sulphate	Fertilizer; Soil conditioner
Potassium	Catalyst; Glass (photochromatic); Heavy water; Nuclear reactor (coolant, alloy with sodium)
Potassium nitrite—derivative of saltpetre (ordinary or potassium)	Preservation (meat)
Pottery clay/ordinary clay/common clay	Glazed tile; Pottery; Rubber (including synthetic rubber); Synthetic cryolite
Pozzolanic clay	Cement (Portland); Mortar
Praseodymium	*See* 'rare earth metals'
Praseodymium compound	*See* 'rare earth metal compounds'
Praseodymium oxide	*See* 'rare earth metal compounds'
Precipitated calcium carbonate or PCC (intermediate product based on milk-of-lime)	Paper (filler for whitening); Sealant
Prehnite	Gem (minor importance); Ornament/jewellery
Producer gas	*See* 'coal-based products'
Propylene	Acrylic; Organic solvents; Pharmaceuticals
Prussian blue (Turnbull's blue)	Paint (pigment and dye)
Psilomelane	Deoxidizer; Desulphurization; Ferro-manganese; Metallurgy (iron, manganese); Silico-manganese; Spiegeleisen
Pyrites	Metallurgy (tin); Oscillator; Radio; Soil conditioning; Sulphur dioxide manufacturing; Sulphuric acid manufacturing
Pyrites—marcasite (trade name, not true marcasite)	Gem; Ornament/jewellery
Pyrites—Copperas/Melanterite	Germicide (disinfectant); Ink; Paint (pigment and dye); Preservation (timber)
Pyrite-based product—Sulphur dioxide	Bleaching (fabric, paper, silk, wool); Paper; Poison (for execution, old practice); Preservation (alcoholic drinks and fruit); Refrigeration (old use); Sugar; Sulphuric acid manufacturing; Sulphurous acid manufacturing; Textile; Wine (antibiotic and antioxidant agent); Winery; Wool

(continued)

Mineral/metals/rocks	Product/process
Pyrite-based product—Sulphuric acid	Acid manufacturing (hydrochloric, nitric, phosphoric etc.); Alum manufacturing; Ammonia (fixing); Bleaching; Cell; Chemicals; Dyeing; Enamel; Fertilizer; Galvanizing; Metallurgy (copper, lead, tin, zinc); Paint (pigment and dye); Pharmaceuticals; Phosphogypsum (byproduct from phosphoric acid manufacturing); Plastics; Refining (petroleum); Tar; Tinning (or tin-plating)
Pyrite-based product—Sulphurous acid manufacture (including sulphur trioxide)	Bisulphite salts (calcium, sodium etc.); Sulphite salts
Pyrochlore (niobium-tantalum ore)	Metallurgy (niobium and tantalum)
Pyrolusite (beta type)	Cement (coloured); Ceramics (including fired tiles, composites, porcelain); Chemicals (*see below*); Electroplating/metal plating; Enamel; Ferrite; Glass; Metallurgy (zinc); Oxidizing agent; Paint (pigment and dye); Synthetic manganese dioxide (chemically activated and electrolytic)
Pyrolusite-based chemical—Hydroquinone (quinol benzene)	Paint (pigment and dye); Pharmaceuticals; Photography
Pyrolusite-based chemical—Manganese borate	Desiccation; Paint (filler); Varnish; Vegetable oil processing
Pyrolusite-based chemical—Manganese carbonate	Animal/poultry feed
Pyrolusite-based chemical—Manganese chloride	Brick (surface colouring); Metallurgy (magnesium)
Pyrolusite-based chemical—Manganese ethylene- bisdithio-carbonate	Paint (pigment and dye); Textile
Pyrolusite-based chemical—Manganese linoleate	Fungicide
Pyrolusite-based chemical—Manganese monoxide	Desiccation; Paint (filler); Varnish; Vegetable oil processing
Pyrolusite-based chemical—Manganese naphthenate	Animal/poultry feed; Fertilizer (plant micronutrient)
Pyrolusite-based chemical—Manganese nitrate	Desiccation; Paint (filler); Varnish; Vegetable oil processing

(continued)

Mineral/metals/rocks	Product/process
Pyrolusite-based chemical—Manganese oxalate	Chemically activated manganese dioxide
Pyrolusite-based chemical—Manganese phosphate	Desiccation; Paint (filler); Varnish; Vegetable oil processing
Pyrolusite-based chemical—Manganese resinate	Preservation (metal—steel)
Pyrolusite-based chemical—Manganese sulphate	Desiccation; Paint (filler); Varnish; Vegetable oil processing
Pyrolusite-based chemical—Manganese sulphide	Fertilizer (plant micronutrient); Metallurgy (manganese)
Pyrolusite-based chemical—Potassium permanganate	Antiknock additive; Disinfectant; Fungicide; Odour control; Oxidizing agent; Pollution control; Sugar; Water treatment (sewerage water)
Pyrolusite (gamma type)	Cell (battery)
Pyrolytic graphite	*See* 'graphite (manufactured)'
Pyrophyllite	Art work (artifact, sculpting, statuary); Ceramics (including fired tiles, composites, porcelain); Cosmetics (including talcum powder); Decoration; Glass; Insecticide/pesticide/germicide/fungicide (carrier); Paint (extender/thinner and filler); Pencil/crayon/writing chalk; Plastics; Refractory; Rubber (including synthetic rubber); Tooth paste
Pyroxenite	Metallurgy (iron); Soil conditioning
Q-metal	*See* 'uranium-238'
Quartz	Adhesive (high temperature); Ceramics (including fired tiles, composites, porcelain); Electronic equipment; Enamel; Ferrosilicon; Fertilizer; Glazing; Grinding (flint pebbles); Halogen/quartz bulb; Microprocessor chip; Paint (pigment and dye); Potash group—potassium silicate; Silicon carbide; Silicon nitride; Silicon recovery; Water filter candle; Welding rod (covering)
Quartz (gem variety)—Agate	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Amethyst	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Aventurine	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Blood stone	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Chalcedony	Gem; Gemmotherapy; Ornament/jewellery

(continued)

Mineral/metals/rocks	Product/process
Quartz (gem variety)—Citrine (false quartz)	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Onyx	Gem; Gemmotherapy; Ornament/jewellery; Onyx flour
Quartz (gem variety)—Plasma	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Rock crystal/crystal quartz	Gem; Gemmotherapy; Lighter (gas, cigarette); Loud speaker; Microphone; Ornament/jewellery; Oscillator; Quartz clock; Radio; Telephone (including portable); Transducer; Ultrasonography
Quartz (gem variety)—Rose quartz	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Smoky quartz	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Star stone/ star quartz	Gem; Gemmotherapy; Ornament/jewellery
Quartz (gem variety)—Tiger-eye	Gem; Gemmotherapy; Ornament/jewellery
Quartz (industrial variety)—Building/ river sand	Brick (sand-lime); Cement (Portland); Construction; Filter/filtration (water); Sand blasting; Stowing (mine); Traction sand (for application on railway tracks)
Quartz (industrial variety)—Foundry/ moulding sand	Mould/sand mould (for metal/alloy casting)
Quartz (industrial variety)—Lasca	Fused quartz
Quartz (industrial variety)—Onyx flour	Synthetic marble
Quartz (industrial variety)—Silica flour	Adhesive (toothpaste); Synthetic marble
Quartz (industrial variety)—Silica fume/ silica dust/fluffy silica/ micro-silica	Cement concrete; Cosmetics (talcum powder); Traction sand (for application on railway tracks)
Quartz (industrial variety)—Silica sand (including frac sand or hydraulic fracturing sand)	Cement (asbestos); Ceramics (including fired tiles, composites, porcelain); Coal washing/beneficiation; Drilling (proppant in oil well); Glass; Polishing (sand paper); Silica flour; Silicon carbide (carborandum); Silicon nitride; Water filter candle; Water glass/liquid glass/sodium silicate; Welding rod (covering)
Quartzite	Metallurgy (iron); Refractory
Radium	Incandescent light; Watch/clock dial (luminescent)
Rare earth metal—Cerium	Carbon arc lighting used in film industry; Catalytic converter; Ceramics (piezoelectric ceramics and ceramic vessels); Glass (coloured); Lighter (gas and cigarette, in alloy with iron); Magnet (permanent, alloy with cobalt); Opacifier

(continued)

Mineral/metals/rocks	Product/process
Rare earth metal—Dysprosium	Fluorescent light; Mercury lamp
Rare earth metal—Erbium	Magnet (permanent)
Rare earth metal—Europium	Cathode ray tube; Coloured lamp; Electronic equipment (computer); Laser/maser; Medical application; Nuclear reactor (moderator); Postage stamp glue; Television (picture tube); X-ray/radiology
Rare earth metal—Gadolinium	Artificial gem (gadolinium-gallium-garnet or GGG); Communication; Garnet (synthetic); Nuclear reactor (moderator, shield and emergency shutdown mechanism); Paint (filler for neutron absorption); X-ray/radiology
Rare earth metal—Holmium	Laser for eye treatment; Magnet; Medical application; Microwave equipment; Nuclear reactor (control rods)
Rare earth metal—Lanthanum	Camera (lens); Capacitor; Communication; Dentistry; Electronic vacuum tube; Hybrid car; Lenses; Semiconductor
Rare earth metal—Lutetium-177	Pharmaceuticals (radiopharmaceuticals or radionuclide); Radiotherapy
Rare earth metal—Mischmetall (intermediate product of mixed rare earth obtained during metallurgy)	Cassette player; Deoxidizer; Desulphurization; Head phone; Lighter (gas and cigarette); Metallurgy (copper, iron, titanium); Video tape recorder
Rare earth metal—Neodymium	Glass (coloured); Laser/maser; Magnet (low-temperature permanent magnet as alloy with boron and iron)
Rare earth metal—Praseodymium	Glass (coloured); Magnet (permanent, alloy with cobalt)
Rare earth metal—Promethium	Specific use yet to be found
Rare earth metal—Samarium	Dentistry; Infrared optics; Magnet (permanent, alloy with cobalt); Phosphor
Rare earth metal—Samarium-153	Radiotherapy
Rare earth metal—Scandium	Fighter jet; Baseball bat; Bicycle frame
Rare earth metal—Terbium	Cathode ray tube; Coloured lamp; Electronic equipment (computer); Fuel cell; Fuel system; Laser/maser; Naval sonar system; Television (picture tube); X-ray/radiology
Rare earth metal—Thulium	Laser/maser
Rare earth metal—Ytterbium	Garnet (synthetic)

(continued)

Mineral/metals/rocks	Product/process
Rare earth metal—Yttrium	Artificial diamond (in combination with aluminium and garnet); Cancer treatment; Cathode ray tube; Ceramics (piezoelectric and ceramic vessels); Coloured lamp; Dentistry; Electronic equipment (computer); Glass (coloured); Laser/maser (in combination with aluminium, and garnet); Led television; Opacifier; Phosphor; Radar (garnet-iron-yttrium composite); Semiconductor; Television (picture tube); X-ray/radiology
Rare earth metal—Yttrium-90	Pharmaceuticals (radiopharmaceuticals or radionuclide); Radiotherapy
Rare earth metal compound—Cerium dioxide	Decolourizer; Glass
Rare earth metal compound—Cerium oxide (ceria)	Catalyst; Cinema (photography and projection); Decolourizer; Fuel cell (for hydrogen generation); Gas mantle (additive to thoria); Glass; Goggles (used by glass blowers); Incandescent light; Lenses; Polishing; Purification/refining/cleaning (petroleum); Searchlight; Television (screen, filter)
Rare earth metal compound—Erbium oxide	Television (filter)
Rare earth metal compound—Europium oxide	Television (screen)
Rare earth metal compound—Gadolinium oxide	Microwave-controlling device
Rare earth metal compound—Lanthanum oxide	Camera (lens); Catalyst; Lenses; Microwave-controlling device; Purification/refining/cleaning (petroleum)
Rare earth metal compounds—Mixed rare earth metal oxides	Ceramics; Glazing; Polishing
Rare earth metal compound—Neodymium carbonate	Decolourizer; Glass
Rare earth metal compound—Neodymium oxide	Catalyst; Goggles (used by glass blowers); Microwave-controlling device; Purification/refining/cleaning (petroleum); Television (filter)
Rare earth metal compound—Praseodymium carbonate	Decolourizer; Glass
Rare earth metal compound—Praseodymium oxide	Catalyst, Goggles (used by glass blowers); Purification/refining/cleaning (petroleum); Television (filter)

(continued)

Mineral/metals/rocks	Product/process
Rare earth metal compound—Yttrium oxide	Television (screen)
Realgar (natural arsenic sulphide)	Paint (pigment and dye)
Red lead/croccoite	Paint (pigment)
Rhenium	Catalyst; Electric bulb; Electroplating/metal plating; Fountain pen nib; Hydrogenation; Jet engine; Photographic flash light; Radio; Rhenium diboride; Spark plug; Spectrophotometer; Superconductor (additive for special properties); Thermocouple
Rhenium diboride	Diamond dressing (potential use)
Rhenium heptasulphide	Catalyst; Hydrogenation
Rhodium (platinum group of metals)	Catalytic converter; Electroplating/metal plating (metal surfaces); Fibre glass (manufacturing machinery, alloy with gold or rhodium); Rayon (manufacturing machinery, alloy with platinum); Searchlight; Thermocouple (alloy with rhenium); Utensils (silverware)
Rhodochrosite	Desulphurization; Metallurgy (iron)
Rhodonite	Gem (minor importance); Ornament/jewellery
River sand	*See* 'sand (river)'
Rock salt/halite	Agriculture/horticulture (harvesting, top dressing of soil); Animal/poultry feed (cattle feed); Bleaching powder; Calcium chloride; Caustic soda; Chemicals (sodium chlorate, perchlorate, hypochlorite); Chlorine and hydrochloric acid; De-icing (road); Disinfectant; Edible salt (including iodized salt and free-flowing table salt); Explosion/explosive (coolant and moderator for use in underground mine); Food processing (bakery, de-boning chicken); Glazing (sodium); Metallurgy (sodium); Preservation (food, fruits, vegetables, timber, leather, hide); Refrigeration (deep freezing); Rubber (synthetic); Salt cake (sodium sulphate); Soda ash/soda (sodium carbonate); Wine (stabilization)
Roofing tile clay	Roofing tile
Rubidium (rubidium-87)	Atomic clock (measures 10^{-18} s); Catalyst (amalgam with mercury); Geological dating; Global Positioning System (GPS); Hydrogenation; Mercury lamp, Radio; Space technology (for synchronization of clocks of satellite and ground monitoring station); Vacuum device
Rubidium iodide	Pharmaceuticals
Ruby	Bearing; Laser/maser; Gemmotherapy; Ornament/jewellery/gem; Skin care
Ruthenium (platinum group of metals)	Gold fabrication
Rutile	Chemicals (*see below*); Gem; Ornament/jewellery; Titanium dioxide (*see below* 'rutile-based chemicals'); Welding
Rutile-based chemical—Alkyl titanate	Waterproofing (nylon, paper, rayon, silk, wood, wool)

(continued)

Mineral/metals/rocks	Product/process
Rutile-based chemical—Titanium tetra chloride	Degasification; Smoke screen; Sky-writing; Metallurgy (titanium)
Rutile-based chemical—Titanous chloride	De-staining; Glass; Leather; Paper; Silica sand beneficiation; Sugar; Textile; Wool
Rutile-based chemical—Titanous sulphate	De-staining; Glass; Leather; Paper; Silica sand beneficiation; Sugar; Textile; Wool
Rutile-based chemical—Titanyl chloride antimony trichloride complex	Fire retardant; Rayon
Rutile-based product (titanium dioxide)	Adhesive; Catalyst; Ceramics; Construction (floor covering); Enamels; Glazing; Hydrogen production (experimental stage); Opacifier; Paint (pigment and dye); Paper; Pharmaceuticals; Rubber (including synthetic rubber); Skin care; Textile
Salt cake (sodium sulphate)	Ceramics (including fired tiles, composites, porcelain)
Saltpetre (ordinary or potassium)	Beverage (coolant); Chemicals; Explosion/explosive/pyrotechnics (gun powder); Fertigation (fertilizer and irrigation combined); Fertilizer; Glass (potash-rich jena glass and lead crystal or flint or cut glass); Ice-cream; Matches; Nitric acid manufacture; Potassium nitrite manufacture; Rocket fuel (propellant); Smoke bomb; Tooth paste/powder
Saltpetre (Chile or nitratine or soda nitre)	Agriculture/horticulture; Enamel; Explosion/explosive/pyrotechnics (dynamite); Fertilizer; Glass; Metallurgy (steel); Nitric acid manufacture; Preservation (meat); Rocket fuel (propellant)
Saltpetre (lime)	Deliquescent; Diesel: Explosion/explosive/pyrotechnics (ammonium nitrate-based explosive); Fertilizer; Incandescent mantle; Matches; Radio
Samarium	*See* ‘rare earth metals’
Samarium-153	*See* ‘rare earth metals’
Sand (granite)	Construction
Sand (river)	*See* ‘quartz—industrial varieties’
Sapphire (also called ‘oriental topaz’, ‘oriental emerald’, ‘oriental amethyst’, ‘Kashmir’ depending on whether colour is yellow, green, purple or cornflower blue respectively)	Bearing; Laser/maser; Gemmotherapy; Ornament/jewellery/gem; Skin care
Scapolite	Gem (minor importance); Ornament/jewellery
Scheelite	Metallurgy (tungsten)
Scrubber gypsum	*See* ‘desulpho-gypsum’

(continued)

Mineral/metals/rocks	Product/process
Seeded aluminium hydroxide gel	Abrasive
Selenium (including its allotropic form 'metallic' selenium)	Aircraft (control system); Camera (exposure meter); EnviroBrass (lead-free brass); Fax machine; Glass (for colouring and decolouring); Metallurgy (copper, steel); Missile; Offset printing; Radio; Rectifier; Rubber (including synthetic rubber), Television; Xerox machine/photocopier
Selenium compounds (Barium selenite, selenium dithiocarbonate, sodium selenite etc.)	Catalyst; Ceramics; Glass (for decolouring); Insecticide/pesticide/germicide/fungicide; Leather; Organic compound manufacture; Oxidizing agent; Paint (pigment and dye); Pharmaceuticals; Plastics; Paper; Rubber; Soaps/detergent/toilet powder
Serpentite	Carbon sequestration; Iron metallurgy; Refractory; Soil conditioning
Shirasu (volcanic eject)	Agriculture/horticulture; Construction (concrete aggregate, plaster); Insulator (heat); Pottery; Soil conditioner
Siderite (after calcination)	Hydrogenation; Metallurgy (iron); Pellets; Vanaspati (butter-like fat of vegetable origin)
Silica flour	*See* 'quartz—industrial varieties'
Silica gel	Degasification; Desiccant; Pharmaceuticals (penicillin)
Silica sand	*See* 'quartz—industrial varieties'
Silico-chrome	Alloy steel; Metallurgy (steel); Stainless steel; Tool steel
Silicomanganese	Deoxidizer; Desulphurization; Metallurgy (steel); Alloy steel (silicon-bearing steel)
Silicon	Electronic equipment; Metallurgy (manganese and tungsten); Microprocessor chip; Photovoltaic/solar cell; Silicon carbide (carborandum); Silicone; Silicon nitride, Silicothermic smelting process; Trichlorosilane
Silicon compound—Silane (silicon tetra-hydride)	Bonding; Microprocessor chip; Sealing
Silicon compound—Silicic acid	Silica gel
Silicon compound—Silicon carbide (carborandum)	Abrasive; Ceramics; Crucible; Cutting; Polishing (hard surfaces); Preservation (metal); Refractory
Silicon compound—Silicon monoxide	Preservation (metal)
Silicon compound—Silicon nitride	Adhesive (high temperature); Ceramics
Silicon compound—Tetra-methyl ortho-silicate	Aerogel/aero-sil/silica aerogel
Silicon compounds—Trichloro-silane	Silane (silicon tetra-hydride); Silicon nitride

(continued)

Mineral/metals/rocks	Product/process
Silicone—Elastomer/silicone rubber	Aircraft; Electric cable; Electric equipment; Gasket; Optical fibre; Sealing; Surgery/surgical material (breast implant); Water-proofing (jacket of core and cladding in optical fibre)
Silicone—Resins	Electric equipment; Insulator (electrical)
Silicone—oils	Injection syringes; Lubricant/grease (ordinary and high temperature); Polishing; Waterproofing (footwear, leather garments, textile)
Silicone—Silli-putty	Art works; Grip strengthener; Toys
Sillimanite	Gem; Gemmotherapy; Ornament/jewellery, refractory
Silver	Aircraft; Ashta Dhatu (8-metal alloy); Bearing; Coinage (alone and alloy with copper); Decoration; Dentistry (amalgam with mercury, tin and copper); Electrical appliances; Electronic equipments (computer); Electroplating/metal plating; Liquid-mirror telescope (for use on moon surface); Medical application; Ornament/jewellery/gem; Silver plate (silver and nickel); Silverware; Soldering (alloy with copper, zinc); Superconductor; Surgery/surgical material (suture wire); Television; Utensils, Varakh (thin edible cover on sweets); Zari; Zari (imitation)
Silver bromide	Photography
Silver chloride	Cell/battery
Sinters	Iron/pig iron
Sintered graphite	*See* 'graphite-based products'
Slaked lime (lime-based intermediate product)	Asphalt (filler for stabilization); Bleaching (bleaching powder); Brick (sand-lime); Leather; Paper manufacturing (waste caustic soda recovery); Textile; Water treatment (sewage water)
Slate granule	*See* 'crushed stone (slate granule)'
Slate powder	*See* 'crushed stone (slate powder)'
Smithsonite	Metallurgy (zinc)
Soda ash or soda (sodium carbonate)	Ceramics (including fired tiles, composites, porcelain); Metallurgy (uranium); Soaps/detergent/toilet powder; Water treatment
Sodalite	Gem (minor importance); Ornament/jewellery
Sodium	Chemicals; Glass (photochromatic); Metallurgy (uranium, zirconium); Nuclear reactor (coolant, alloy with potassium); Sodium lamp; Tetraethyl lead (based on lead-sodium alloy)
Sodium carbonate	*See* 'soda ash'
Sodium iodide	Scintillation counter (activated by thallium)
Sodium lignite	*See* 'causticized lignite/sodium lignite'
Sodium silicate	*See* 'water glass/liquid glass/sodium silicate'
Sodium sulphate	*See* 'salt cake'
Sodium tungstate	Fire proofing; Textile
Sphalerite	Metallurgy (zinc)
Sphene	Gem (minor importance); Ornament/jewellery
Spiegeleisen	Metallurgy (steel)
Spinel (blue)	Gem; Gemmotherapy; Ornament/jewellery
Spinel (red)	Gem; Gemmotherapy; Ornament/jewellery
Spodumene (lithium mineral)	Ceramics; Glass; Glazing; Metallurgy (lithium)

(continued)

Mineral/metals/rocks	Product/process
Sponge (directly reduced) iron	Steel
Staurolite	Gem; Gemmotherapy; Ornament/jewellery; Sand blasting
Steel	Alloys of steel; Nitrided steels; Stainless steel
Stellite	Cutting/boring;
Stibnite (natural antimony sulphide)	Cosmetics ('Surma' for application to eye and eye brow); Metallurgy (antimony)
Stoneware clay	Ceramics (including fired tiles, composites, porcelain); Pipe (sewerage); Stoneware for chemical; Stoneware crockery
Stratlingite	Mortar (strengthening material)
Strontianite	Strontium carbonate; Strontium hydroxide; Strontium metallurgy; Strontium nitrate; Strontium oxalate; Strontium peroxide; Strontium titanate
Strontium and its alloys	Degasification; Electronic equipment; Ferrite
Strontium carbonate	Glass
Strontium hydroxide	Beet sugar
Strontium nitrate	Night illumination; Pyrotechnics; Signal device; Tracer bullet
Strontium oxalate	Night illumination; Pyrotechnics; Signal device; Tracer bullet
Strontium peroxide	Night illumination; Pyrotechnics; Signal device; Tracer bullet
Strontium titanate	Hydrogen production (experimental stage); Synthetic diamond
Sugar of lead	*See* 'lead compounds'
Sulphur	Adhesive; Carbon disulphide; Ebonite; Enamel; Explosives (gunpowder); Flower of sulphur; Hydrogen sulphide; Matches; Metallurgy (magnesium); Pyrotechnics (fireworks); Rubber (including synthetic rubber), Soil conditioning; Sulphur dioxide manufacturing; Sulphuric acid manufacturing; Ultramarine
Sulphur-based product—Carbon disulphide	Rayon; Solvent (industrial)
Sulphur-based product—Flower of sulphur	Insecticide/germicide
Sulphur-based product—Hydrogen sulphide	Analytical chemistry
Sulphur-based product—Methyl mercaptan (or methyl sulphydryl)	Natural gas (additive)
Sulphur-based product—Sulphur dioxide	Bleaching (fabric, paper, silk, wool); Paper; Poison (for execution, old practice); Preservation (alcoholic drinks and fruit); Refrigeration (old use); Sugar; Sulphuric acid manufacturing; Sulphurous acid manufacturing; Textile; Wine (antibiotic and antioxidant agent); Winery; Wool

(continued)

Mineral/metals/rocks	Product/process
Sulphur-based product—Sulphuric acid	Acid manufacturing (hydrochloric, nitric, phosphoric etc.); Alum manufacturing; Ammonia (fixing); Bleaching; Cell; Chemicals; Enamel; Fertilizer; Galvanizing; Paint (pigment and dye); Pharmaceuticals; Phosphogypsum (byproduct from phosphoric acid manufacturing); Photography (hypo); Plastic; Refining (nonferrous metals, petroleum); Tinning (or tinplating)
Sulphur-based product—Sulphurous acid (including sulphur trioxide) manufacturing	Bisulphite salts (calcium, sodium etc.); Sulphite salts
Sunstone	*See* 'Feldspar (sunstone)'
Synthetic graphite	*See* 'manufactured graphite'
Synthetic manganese dioxide	Cell (battery)
Synthetic rutile	Paint (pigment and die); Synthetic diamond
Taconite	Pellets; Metallurgy (iron)
Talc/French chalk/ steatite/soapstone	Ceramics (including fired tiles, composites, porcelain); Cordierite (artificial); Cosmetics (talcum powder, cream etc.); Decoration (including art work, artifact, statuary); Electric cable; Electro-ceramics; Explosion/explosive/pyrotechnics (gun powder); Forsterite manufacture; Insecticide/pesticide/germicide/fungicide; Lubricant/ grease; Paint (extender/thinner and filler); Paper manufacture; Pencil/ crayon and writing chalk; Pharmaceuticals; Plastics; Polishing (delicate substances including rice, corn etc.); Refractory bricks (insulation bricks); Rubber (including synthetic rubber); Sanitary ware (unfired); Sealing/lining, Synthetic/imitation marble; Textile
Tantalite	Die casting (wire drawing); Metallurgy (niobium, tantalum)
Tantalum	Capacitor; Chemical equipment; Condenser (electrical); Degasification; Dentistry (instruments); Electronic equipment; Fountain pen nib; Jet engine; Radio; Rectifier; Surgery/surgical material (cranial plates, screw, suture wire); Vacuum device
Tantalum carbide	Cutting/boring; Die (in combination with tungsten carbide, for wire drawing): drilling)
Tantalum oxide	Aircraft (lens); Camera (lens)
Tar sand	*See* 'asphaltic rock/natural bitumen'
Tellurium	Ceramics (including fired tiles, composites, porcelain); Electrical appliances; Foundry (metal casting); Glass; Metallurgy (copper, steel); Rubber (including synthetic rubber)
Terbium	*See* 'rare earth metals'
Terracotta clay	Decoration (including art work, artifact); Terracotta articles
Terracotta shale	Decoration (including art work, artifact)
Tetraethyl lead	Antiknock additive
Thallium	Glass, Scintillation counter (thallium-activated sodium iodide); Soldering (additive to lead-tin alloy); Thermometer (low temperature, alloy with mercury)
Thallium bromo-iodide	Infrared optics; Signalling device; Spectrometer

(continued)

Mineral/metals/rocks	Product/process
Thallium carbonate	Insecticide/pesticide/germicide/fungicide (spray)
Thallium oxides	Glass
Thallium oxysulphide	Camera (exposure meter); Photovoltaic/solar cell
Thallium sulphate	Rodenticide
Thorium (thorium-232)	Camera (lenses); Catalyst; Cathode ray tube; Chemicals; Deoxidizer; Electric bulb (filament, alloyed with tungsten); Electrode; Glass (optical); Lenses; Mercury lamp; Metallurgy (iron, molybdenum); Photoelectric cell (battery); Radio (bulb); Synthetic petroleum (alloy with cobalt); Uranium-233; Welding (alloyed with tungsten); X-rays/ radiology
Thorium nitrate	Gas mantle
Thorium oxide (thoria)	Crucible; Electric bulb (added to tungsten); Gas mantle; Paint (luminescent paint)
Thulium	*See* 'rare earth metals'
Tiger-eye	*See* 'quartz—gem varieties'
Tin	Ashta Dhatu (8-metal alloy); Automotive parts (engine); Babbitt metal (alloy with antimony and copper); Bell metal (along with copper); Britannia metal (along with antimony); Bronze; Bullet/shot/ shell; Canning/packaging; Chemicals (*see below*); Decoration (tin powder); Dentistry (amalgam with silver, mercury and copper); Electroplating/metal plating; Foils (for wrapping food etc.); Glass (float glass); Gun metal (admiralty bronze); Lipowitz's metal (alloy with bismuth and lead); Metallization/metal powder; Naval brass; Newton's metal (alloy with bismuth and lead); Pancha Dhatu (5-metal alloy); Pewter (alloy with antimony and lead); Porous bronze; Preservation (food); Printing type metal (alloy with antimony, copper and lead); Roofing material; Rose's metal (alloy with bismuth and lead); Safety fuse (fuse wire, both pure tin and its alloy with bismuth, cadmium and lead); Safety plug (alloy with bismuth, cadmium and indium); Soldering (along with lead), Spinoidal alloy (with copper and nickel); Superconductor (alloy with niobium, titanium); Terne plating (for roofing sheet); Tinning (tin-plating); Tube (collapsible); Water sprinkler (automatic, alloy with bismuth, lead, cadmium); Wine bottle cap; Wood's metal (along with bismuth, cadmium and lead)
Tin-based chemical—Indium tin oxide	Electronic equipment (computer screen)
Tin-based chemical—Organo-tin compounds (including tin oleate)	Electrical equipment (transformer oil); Lubricant/grease; Paint (filler); Pharmaceuticals; Textile (oils); Vinyl sheet (PVC)
Tin-based chemical—Potassium stannate	Electronic equipment
Tin-based chemical—Stannic oxide	Aircraft (windshield of 0.1 micron thick glass); Cathode ray tube; Enamel; Fluorescent light; Glass (thin glass of 1 micron thickness); Opacifier
Tin-based chemical—Stannous chloride	Catalyst; Purification/refining (edible oil); Sericulture (weighting agent for silk)

(continued)

Mineral/metals/rocks	Product/process
Tin-based chemical—Stannous sulphate	Electronic equipment
Tin-based chemical—Zinc hydroxyl stannate and stannate	Fire retardant; Smoke inhibitor
Titanium	Abrasive; Aircraft; Automotive part (door); Chemical equipment; Ceramics; Cutting; Magnet (permanent); Nitinol (nickel-titanium alloy); Rocket fuel; Space technology (including rocket, satellite, spacecraft); Sports car; Stainless steel manufacturing; Submarine; Superconductor (alloy with tin, niobium); Titanium carbide; Transistor
Titanium dioxide	*See* 'Rutile-based product'
Toluene	Explosion/explosive (trinitrotoluene or TNT); Nylon; Perlon
Topaz	Gem; Gemmotherapy; Ornament/jewellery
Tourmaline	Decoration (including art work, artifact); Fertilizer (plant micronutrient, boron measurement), Manometer; Optical instruments (type of polariscope called 'tourmaline tongs'); Thermal dosimeter
Tourmaline (gem variety)—Achroite	Gem; Gemmotherapy; Ornament/jewellery
Tourmaline (gem variety)—Brazilian sapphire	Gem; Gemmotherapy; Ornament/jewellery
Tourmaline (gem variety—Indicolite	Gem; Gemmotherapy; Ornament/jewellery
Tourmaline (gem variety)—Rubellite	Gem; Gemmotherapy; Ornament/jewellery
Tourmaline (gem variety)—Schorl	Gem; Gemmotherapy; Ornament/jewellery
Tourmaline (gem variety)—Verdelite	Gem; Gemmotherapy; Ornament/jewellery
Trona	Soda ash or soda (sodium carbonate) recovery
Tungsten	Chemicals; Electrical bulb (filament); Electric equipment; Horn (electric); Metallization/metal powder; Nuclear reactor; Rectifier; Sealing/lining (for borosilicate glass to metal contact); Spark plug; Speed governor; Stellite (alloy with chromium and other metals); Tungsten carbide; Welding; X-ray/radiology
Tungsten bronze (tungstic oxide or WO_3)	Paint (pigment)
Tungsten carbide	Bullet/shot/shell (heavy armour-piercing shell); Cutting/boring; Die (in combination with tantalum carbide, for wire drawing); Drilling; Ornament/jewellery
Tungsten sulphide	Lubricant/grease (high temperature)
Turquoise	Gem, Gemmotherapy, Ornament/jewellery
Ulexite (boron mineral)	Boric acid; Glass (optical fibre glass)

(continued)

Mineral/metals/rocks	Product/process
Uranium	Uranium-235 recovery (after its enrichment); Uranium-238 separation (after recovering enriched uranium- 235)
Uranium-233 (converted from thorium)	Nuclear reactor
Uranium-235 (including alloys)	Cobalt-60 from cobalt; Fission bomb/atom bomb; Nuclear reactor (alone and alloy with antimony, bismuth, boron-11); Submarine; Transportation (ocean)
Uranium-238 (depleted uranium or DU or Q-metal or depletalloy or D-38)	Aircraft (counterweight); Containers for radioactive material; Geological dating; Glass (coloured); Malaria control; Missile (high density projectile); Plutonium-239 production; Radiography; Radiotherapy (shielding)
Uranium-sodium oxide, uranium-ammonium oxide, uranyl sulphate and nitrate, uranates etc.	Calico printing; Ceramics (including fired tiles, composites, porcelain); Chemicals; Glass; Glazing; Leather; Mordant; Textile
Uranium dioxide	Nuclear reactor (fuel element)
Uranium carbide	Nuclear reactor (fuel element); Nuclear reactor (fast breeder)
Uranium nitrate	Nuclear reactor (fuel element)
Uranium sulphate	Nuclear reactor (fuel element)
Vanadium	Chemicals, Metallurgy (steel); Nuclear reactor (fuel element cladding)
Vanadium-based chemical—Ammonium metavanadate	Electrical appliances; Glass; Glazing; Ink (printing); Paint (filler, pigment); Pharmaceuticals; Textile
Vanadium dioxide	Glass (window)
Vanadium pentoxide	Ammonia synthesis; Catalyst; Electrical appliances; Ferrovanadium; Glass; Glazing; Ink (printing); Paint (filler, pigment); Pharmaceuticals; Sulphuric acid manufacturing; Textile
Varnish	Polishing
Vermiculite	Annealing steel (unexfoliated vermiculite); Board/panel; Construction (aggregate, concrete, structural material); Drilling (unexfoliated vermiculite); Fertilizer; Fireproofing; Glass; Hydroponics; Insecticide/pesticide/germicide/fungicide; Insulator (heat); Insulator (sound); Lubricant/grease; Packing; Paint filler (for special properties); Plastics; Refractory; Sealing/lining; Soil conditioning
Water gas (blue water gas)	*See* 'coal-based products'
Water gas (carbureted)	*See* 'coal-based products'
Water glass/liquid glass/sodium silicate	Adhesive; Board; Bonding; Cement; Construction (concrete); Fireproof; Paper; Preservation (egg, timber); Purification (toxic liquids); Sealing; Silicic acid (silicon compound); Soaps/detergents; Stucco; Water treatment

(continued)

Mineral/metals/rocks	Product/process
Wax/paraffin wax (petroleum refinery product)	Art work (model-making); Candle; Edible fat; Grease; Insulator (electrical); Matches (sticks); Paper (glazed); Polishing (boot, delicate objects); Preservation (egg, electrical cable, stones); Soaps/detergent (synthetic detergent); Waterproofing
Weldite (Alloy of aluminium and lithium)	Aircrafts; Space technology
White arsenic	*See* 'arsenic-based compounds'
White carbon	*See* 'graphite (manufactured)'
White metal	Bearing
White oil (petroleum refinery product)	Cosmetics; Degasification; Disinfectant; Hair oil; Perfumery; Pharmaceuticals; Preservation (metal, surgical instruments); Skin care
White spirit	Dry cleaning; Paint (extender/thinner); Perfumery (extraction from flowers)
Willemite	Metallurgy (zinc)
Wolframite	Metallurgy (tungsten)
Wollastonite	Adhesive; Brake/friction material; Ceramics (including fired tiles, composites, porcelain); Electrode; Glazing; Mineral wool/rock wool; Paint filler (for special properties); Plastics; Refractory; Rubber (including synthetic rubber)
Xenotime	Metallurgy (rare earth metals)
Xylene	Chemical reagent
Ytterbium	*See* 'rare earth metals'
Yttrium	*See* 'rare earth metals'
Yttrium-90	*See* 'rare earth metals'
Zeolite	Agriculture/horticulture; Asphalt; Animal/poultry feed; Beet sugar; Carbon sequestration; Catalyst; Cement; Fishery; Floriculture; Glass (perfect glass); Hydroponics; Nuclear waste treatment; Insecticide/pesticide/germicide/fungicide (including carrier); Odour control; Paper; Purification/refining/cleaning (edible oil, gases, natural gas, oxygen and toxic liquid); Refrigeration; Soaps/detergent/toilet powder; Silviculture; Soil conditioning; Solar heating; Water treatment; Zeoponic materials (chemically modified natural zeolite with enhanced efficiency)
Zeolite (synthetic)	Chemical sensor: Optical instruments; Polymer filament; Soaps/detergents
Zeolite (thomsonite)	Gem; Ornament/jewellery
Zinc	Brass; Cell/battery (alkaline battery and dry cell); Chemicals (*see below*); Damascene art; Die casting; EnviroBrass (lead-free brass); Foundry (metal casting); Galvanizing; German silver; Metallurgy (gold and silver); Naval brass; Pyrotechnics (fireworks)
Zinc-based chemical—Cobalt-zinc oxide (cobalt green)	*See* 'cobalt chemicals'

(continued)

Mineral/metals/rocks	Product/process
Zinc chromate	*See* 'chromite-based chemical'
Zinc oxide	Ferrite; Rubber
Zinc peroxide	Paint (filler); Titanium dioxide (rutile-based product)
Zinc sulphate	Desiccation (oil); Plant nutrient (micronutrient)
Zinc sulphido-silicate	Fluorescent light application
Zincite	Metallurgy (zinc)
Zircon/zirconia	Abrasive/grinding (wheel, paper, cloth); Artificial diamond; Ceramics (including fired tiles, composites, porcelain); Chemicals; Crucible; Dentistry; Electroceramics; Enamel; Foundry (metal casting); Fountain pen nib; Fuel cell (battery); Geological dating; Glass; Glazing; Insulator (electrical); Lacquer filler; Leather filler; Opacifier; Oxygen sensor; Paint filler; Polishing; Refining (beer); Refractory; Rubber (white) filler; Semiconductor; Zirconium metallurgy
Zircon (hyacynth)	Gem; Gemmotherapy; Ornament/jewellery
Zircon (jargon)	Gem; Gemmotherapy
Zircon (starlite)	Gem; Gemmotherapy
Zirconium carbonate	Pharmaceuticals
Zirconium phosphate	Cosmetics (antiperspirants, ointments)
Zirconium	Aircraft; Cutting tools; Degasification; Deoxidizer; Desulphurization; Domestic heating apparatus; Explosion/explosive/pyrotechnics (including gun powder, dynamite); Fountain pen nib; Limelight; Magnet (low-temperature); Nuclear reactor (cladding and heat transfer); Photographic flashlight; Steel metallurgy; Superconductor; Surgery/surgical material; Textile machine; Vacuum device
Zoisite (Tanzanite)	Gem; Ornament/jewellery
Zoisite (Thullite)	Gem; Ornament/jewellery

Glossary

Adb Air-dried basis.

Adhesive An adhesive is an inorganic or organic substance capable of bonding other substances together by surface attachment.

Agglomeration Agglomeration techniques include sintering, briquetting and pelletizing.

Albedo Albedo is a measure of the reflecting power i.e. the ratio of reflected light to the incident light. It is indicated in a scale of 0–1.

Alkylation Alkylation is the coupling of an olefin and a butane (or isobutane) over a catalyst.

Alloy An alloy is a metallic material consisting of atoms of two or more metals, or two or more elements of which most of the atoms are metal atoms. Thus, even a non-metal can be an element in an alloy. In an alloy, the elements are admixed at the atomic level, and most of the properties are those usually associated with metals. An alloy differs from a chemical compound inasmuch as there is no fixed formula in the former, and the contents of the elements can be varied and manipulated depending on the desirable properties to be achieved.

Amalgamation Amalgam is a kind of plastic alloy of mercury with gold, silver, tin etc. and the process of such alloying is called amalgamation.

Atomization Atomization is the process of dispersion of a molten metal into small particles by a rapidly moving stream of gas or liquid.

Base exchange saturation Base exchange saturation of soil is the ratio [Exchangeable (Ca + Mg)]/[(Ca + Mg + Al + H) extracted from soil].

Base exchanging power It means the quantity of positively charged ions (cations) that a clay mineral can accommodate on its negatively charged surface, and it is expressed as milli-equivalents per 100 g. This is also called cation exchange capacity.

Baumé scale Named after its inventor Antoinne Baumé, Baumé scale is a quick technique for measuring specific gravity of liquids with the help of a hydrometer (a hollow sealed calibrated glass tube). It comprises two independent mutually exclusive scales—one for liquids with specific gravity less than 1 (i.e., lighter than

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water) and the other for those with specific gravity greater than 1 (i.e., heavier than water). On this scale, the specific gravity denoted by the unit '°Bé', and the reference liquid for comparison is a solution of NaCl. The principle consists in measurement of the depth to which the hydrometer sinks when immersed in a liquid. The two scales are calibrated and they can be converted to specific gravity as follows:

(a) For liquids heavier than water: 0 °Bé = distance the hydrometer sinks in pure water, and 15 °Bé = distance the hydrometer sinks in a solution of 15 % NaCl by mass. Its conversion factor to specific gravity at 15 °C is

$$\text{Specific gravity} = 145/(145 - {}^{\circ}\text{Bé})$$

(b) For liquids lighter than water: 0 °Bé = distance the hydrometer sinks in solution of 10 % NaCl by mass, and 10 °Bé = distance the hydrometer sinks in pure water. Its conversion factor to specific gravity at 15 °C is

$$\text{Specific gravity} = 140/(130 + {}^{\circ}\text{Bé})$$

The Baumé scale is popular for measuring and expressing specific gravity of wine and brine.

Becquerel Becquerel is a measure of the rate (not energy) of radiation emission from a source per second. 1 Becquerel = 27 pico-curie.

Biscuit firing In ceramics, the fired product before glazing is called biscuit and the firing is called biscuit firing.

Brightness Brightness is measured in terms of the reflectance of blue wave of light (wave length 457 μ).

Briquette Briquettes are made by pressing the fines with or without bonding material.

Bursting expansion When the molten metal oxide in a furnace enters into the grains of the refractory bricks through the micro-fractures and tends to crystallize, the tremendous force of crystallization results in bursting of the bricks, and this phenomenon is known as bursting expansion.

Capacitors Capacitors store electricity for a short period of time and ensure that the current supplied remains within narrow range of parameters – particularly in low voltage applications.

Carbon credit A carbon credit is a unit that measures a specific amount of reduction of green house gases (GHG). These credits are generally represented as a GHG reduction equivalent to a tonne of carbon dioxide or carbon or methane.

Catalyst A catalyst increases the rate of chemical reactions without itself undergoing permanent change.

Cation exchange capacity It means the quantity of positively charged ions (cations) that a clay mineral can accommodate on its negatively charged surface, and it is expressed as milli-equivalents per 100 g. This is also called *Base exchanging power*.

Cenosphere Cenosphere is a silicate glass filled with nitrogen and CO_2, and it is produced due to conversion of a portion of the fly ash during the combustion process.

Chelating agent It surrounds and holds the unwanted ions of the water-hardening substances calcium and magnesium, thus softening the water.

Chrome It is a component of colour. It indicates the degree of departure of a particular hue from neutral grey of the same value. In other words, it indicates the degree of saturation of the hue with reference to neutral grey. Thus, the familiar terms like 'weakly red', 'strong red', 'deep red' etc. are expressions of chrome.

Clay ironstone Clay ironstone is a general term given to a ferruginous mineral occurring in the form of concretionary structures embedded in beds of clay or shale. The ferruginous mineral may be either siderite or hematite or limonite.

Coefficient of friction It is the ratio of the friction force to the applied force. It acts perpendicular to the applied force. Higher the coefficient more is the energy loss due to friction.

Coercive force Coercive force is the demagnetizing force required to reduce magnetic flux density of a magnet to zero.

Compressive strength It is the load per unit area under which a block fails by shear or splitting. It is resistance to volume stress that tends to produce change in volume. It is expressed in terms of pounds per square inch (psi) or kg/cm^2.

Corrosion Corrosion is the degradation of a material by the environment, most people associate with rust.

Cracking In 'cracking', molecules are broken down under high temperature (with or without a catalyst) into smaller units, and a new type of hydrocarbon namely olefin is produced. By cracking, light gases, petroleum coke, fuel oil etc. can also be produced.

Creep Creep is a time-dependent deformation, and it is the result of constant stress conditions over a long period of time. Ordinarily, the term is restricted to deformation resulting from stresses below the elastic limit.

Critical mass It means a size, number or amount large enough to generate self-sustaining social momentum to create further growth.

Curie It is a unit of radioactivity equal to the amount of a radioactive isotope that decays at the rate of 37 billion disintegrations per second.

Curie temperature Curie temperature is the temperature above which a substance loses its magnetism.

Darcy *See* 'Permeability'.

Decarburization Decarburization is the process of removal of carbon by heating in an atmosphere in which the concentration of decarburizing gases exceeds a certain value.

Diamagnetic materials These cause the magnetic flux to move further apart, resulting in decrease in magnetic flux density compared to vacuum, the magnetic permeability of which is taken as the unit value.

Dielectric constant It is the ratio of the capacitance of a specific sample of the material between two plates and a vacuum between the same plates. Stronger the electrical conductivity, higher is the dielectric constant. The value for air, one of the poor conductors of electricity, is 1.

Dielectric strength Dielectric strength is a measure of the electrical insulation, and is the voltage that an insulating material can withstand before break-down. It is expressed in terms of specific resistance. The unit of measurement is volts/mm.

Dispersion Dispersion is the rate of change of refractive index with change in wavelength of the incident light, and is expressed with reference to some wavelength.

Dyne The word has been derived from the Greek word "dynamics". It is smaller unit for force than Newton. One dyne is the force required to produce an acceleration of one centimetre per second per second to a mass of one gram. It is 100000th of a Newton.

Electric energy It refers to the total storage capacity of a system or amount of power supplied or used in a length time. Its units of measurement are megawatt-hour (MWh), kilowatt-hour (KWh) etc.

Electric power It is the amount of electricity a storage capacity can absorb or supply at any given instant i.e. rate of energy supplied or used. Its units of measurement are megawatt (MW), kilowatt (KW) etc.

Electrolysis If a strong electric current is passed through a chemical compound, its decomposition into elements or parts takes place. This is called electrolysis.

Electronegative element Atoms of some elements collect in the positive pole or anode, and those elements are called electronegative.

Electron emission Electrons present in the crystal lattices on the surface of a metal can be liberated by the addition of energy, in different forms such as light rays (photoelectric emission), heat (thermionic emission) or electric current (field emission) etc. The external energy agitates the atoms of the metal; as a result high-energy electrons overcome the intra-atomic forces, break out from the surface of the metal and escape. This is the principle of electron emission.

Electrophoresis Electrophoresis is the movement of an electrically charged substance under the influence of an electric field. *Gel electrophoresis* is a technique used for the separation of DNA, RNA or protein molecules through an electric charge and is used for analytical purpose and as a preparation technique to partially purify molecules prior to use of other methods such as mass spectrometry, DNA sequencing etc.

Electroplating Electroplating is the process of precipitating a metal in an anodizing bath through electrolysis.

Electropositive element Atoms of some elements collect in the negative pole or cathode, and those elements are called electropositive.

Emery Emery is a natural mineral comprising an intimate mixture of magnetite and corundum used in powder form for polishing, smoothing and grinding purposes. On an average, emery contains Al_2O_3 65 % (min), magnetite 22 % (max) and SiO_2 10 % (max).

Emissivity Emissivity is a measure of the energy (heat or some other form) appearing within a substance due to absorption of incident light. A perfectly black substance absorbs all the incident light, converts it into some radiation energy and may emit the same and its emissivity is reckoned as '1'. This serves as the reference standard. Since all the non-black objects absorb less light than a black one, their emissivity is always less than '1'.

Emulsion An emulsion is a dispersion of liquid in another immiscible liquid.

Equivalent weight It is the molecular weight of an element divided by its valency.

Eutectics The constant proportion in which two constituents of a binary magma or a binary melt simultaneously crystallize, is called the eutectic.

Fatigue limit Also called endurance limit, it is defined as the limiting stress below which a specimen can withstand hundreds of millions of repetitions of stress without fracture.

Ferrite Ferrites are mixed oxide ceramics, which show magnetic properties similar to those of iron.

Ferrocene First prepared in 1951, it is an organo-metallic compound of iron i.e. dicyclo-pentadienyl iron [$Fe(C_5H_5)_2$].

Ferromagnetic materials These are either naturally magnetic or attracted to a magnetic field, and may be easily magnetized.

Fission The ability of an atom to split due to collision with a free neutron is called 'fission'.

Fluorescence Atoms of some luminescent materials emit light only during their exposure to exciting energy and they are called fluorescent.

Gauss Named after a German mathematician, it is a unit of magnetic flux density equal to 1 Maxwell per square centimetre.

Gems and gemstones According to Webster's Second Edition Unabridged Dictionary, gem means any jewel having value and beauty that is intrinsic and not derived from its setting; and gemstones or gem materials are stones or materials from which a gem may be cut. By popular perception, a gem is a rarely encountered hard, durable, brilliantly shining and beautiful natural mineral which has high intrinsic value.

Glazing The purpose of glazing is to provide a uniform firmly adhering coating on the surface of the ceramic body concealing defects such as pinholes, bubbles etc. Glaze may be *raw glaze* or *fritted glaze*. Raw glaze consists of insoluble material applied as such (soluble components crystallize in the mixture and cause blemishes on the treated surface), while fritted glaze is heated beforehand to cause chemical change in the components. Glaze should not only melt but also spread uniformly.

Gloss/reflectivity Gloss is the percentage of the incident light beam that is reflected from a surface.

Glost firing Firing of a glazed product which has previously been fired at a higher temperature is called glost firing.

Gravel According to the definition of the American Society of Testing Materials (ASTM), gravel is naturally occurring unconsolidated or poorly consolidated rock particles ranging in size from 4.75 to 76.2 mm. But according to many sedimentary petrologists, granular gravels are of 2–4 mm size and gravels, more than 4 mm.

Gross calorific value Gross calorific value is the total amount of heat obtainable by the combustion of a given coal. Its units are kilocalorie and British Thermal Unit or BTU. Kilocalorie denotes the number of kilograms of water which may be heated through 1 °C, in the neighbourhood of 15 °C, by the complete combustion of 1 kg of coal. BTU denotes the number of pounds of water which may be heated through 1 °F, in the neighbourhood of 60 °F, by the complete combustion of 1 lb. of coal. In either of these cases, the conditions are: (i) coal is dried at 105 °C until its weight becomes constant, (ii) whole of heat is transferred without loss to the water, and (iii) the products leave the system at the atmospheric temperature and pressure.

Half life The period in which the number of atoms of a radioactive substance decreases to one half its original value (with proportional increase in the mass of lead produced) is called 'half-life'.

Hardenability Hardenability is different from hardness, and it relates to the ease with which steel or any other metal or alloy will harden and the depth of hardening obtainable. Its unit is the same as that of length.

Hard magnets Once magnetized, these magnets retain their magnetic field indefinitely even after the magnetizing field is withdrawn. These are also called *permanent magnets*.

Heat transfer coefficient It is the amount of heat transferred per unit time per unit area per unit temperature difference.

Heterotrophic Plate Count (HPC) Heterotrophs are bacteria that thrive on carbon and nitrogen of organic compounds. HPC is a microbial contaminant indicator and is a measure of the total number of bacteria that will form colonies during a period of incubation in a nutrient. Its unit is cfu/ml i.e., colony-forming units per millilitre.

Hue It is a component of colour. The much familiar terms like red, blue, orange etc. denote hue (or the type of colour).

Hydroponics It is a technique of growing plants without soil, in water containing dissolved nutrients.

Hyporheic zone It refers to the transition zone in which close interactions between ground water and surface water take place (e.g. wetland).

International Annealed Copper Standard or IACS This is the international standard for electrical conductivity with value of conductivity 2.8 $\mu\Omega/cm^3$ at 20 °C.

Iron carbide Iron carbide (Fe_3C) is reduced iron oxide with 5–6 % chemically fixed carbon. It is a direct feed for steel-making.

Isomerization Isomerization is the process of producing a similar but new substance by rearrangement of atoms within the hydrocarbon molecules of the original substance.

LAB parameters The three letters 'l', 'a' and 'b' are used as parameters for denoting colours—'l' value stands for whiteness; 'a+' value, for red colour; 'a–' value, for green colour; 'b+' value, for yellow; and 'b–' value stands for blue colour.

Langelier Saturation (or Stability) Index (LSI) Langelier Saturation (or Stability) Index or LSI values are calculated for a precise quantification of the hardness of water which is caused by the presence of the insoluble carbonates and sulphates of calcium and magnesium, which tend to precipitate in the form of scales when the water is boiled. With the help of LSI value of a water, it can be predicted whether it will precipitate or dissolve or be in equilibrium with $CaCO_3$ which is then converted to a scale of hardness. In this, the pH of a sample of water saturated with $CaCO_3$ is pre-calculated as a reference (pH_s) and then the pH of the test sample of water (pH_w). LSI is the difference ($pH_w - pH_s$). LSI value of '0' means equilibrium, a negative value means no scaling potential (soft water) and a positive value means high scaling potential (hard water).

Levigation Levigation is the operation involving pulverization of clay to very fine size for liberating the clay particles from the impurities.

Lixiviation Lixiviation (also called leaching) is the process of separating a soluble substance from one that is insoluble, by washing with water or some solvent.

Luminescence Many substances easily gain energy and emit light without being heated very much. They do this through a process called luminescence.

Magnetic flux These are the lines of force conceived as a flow from one pole of the magnet to another (counterpart of current in electricity). Its unit of measurement is gauss (or Maxwell per cm^2) which is the magnetic flux perpendicularly intersecting an area of one square centimetre.

Magnetic permeability It is the ability to acquire magnetism in a magnetic field. Magnetic permeability of vacuum is taken as the unit value.

Mesh size It represents number of holes per square inch of area on a sieve. Approximately, 1250 mesh is equivalent to 10 μm and 125 mesh to 100 μm.

Metallization Metallization is the reciprocal of reducibility and is expressed in terms of percentage of ore reduced to metal. Metallization also signifies the process in which very small globules of a liquid metal are blown by a spray gun and sprayed on other metal surfaces, so that the molten globules of the sprayed metal immediately solidify and interlock by flattening.

Metal matrix composites A composite material is a materials system composed of a mixture of two or more materials deliberately combined to form heterogeneous structures with desired or intended properties. In composites, at least one of the constituents serves principally to strengthen or reinforce the composite, while another constituent, called the applications matrix, serves to confine the reinforcing constituent(s) and provides a means to distribute any applied stress. In metal matrix composites (MMCs), a metal serves as the matrix, while the reinforcing constituent can be a metal, a non-metal, an alloy or a compound.

Mineral wool Mineral wool is a general term meaning fibres made from inorganic substances that may include minerals, rocks and metal oxides—synthetic or natural. Glass wool, lime wool, rock wool or stone wool, slag wool are all different types of mineral wool.

Modulus of elasticity The maximum stress to which a body can be subjected without permanent deformation is called its *elastic limit*. According to *Hooke's Law*, within the elastic limit, stress is directly proportional to strain, and the constant ratio stress/strain is called *modulus of elasticity*. It is usually expressed in units of psi or kg/cm^2. Corresponding to the three kinds of force—tensile, compressive and shearing—there are three kinds of stress and strain and three kinds of modulus of elasticity. These three elastic moduli are:

(i) Young's modulus
(ii) Bulk modulus and
(iii) Modulus of rigidity

Net calorific value Net calorific value is the gross calorific value minus the heat liberated by the condensation of the steam produced on combustion and the subsequent cooling of this condensed steam to water down to atmospheric temperature (15 °C or 60 °F).

Newton Newton or 'N' is a unit of force. One Newton is the force required to produce an acceleration of one metre per second per second to a mass of one kilogram. Compressive strength is expressed as N/mm^2.

Nitrided steel Nitrided steel or *alloy nitride steel* or *nitralloy* is a steel which is processed so that nitrogen is absorbed by the surface which becomes intensely surface hardened, yet machinable.

Non-stoichiometric compound It is a compound in which a fraction of given atom is either missing or in excess.

Octane number Octane number is a measure of 'anti-knock' value of a motor fuel i.e. the ability to resist the knock or sound produced due to its sudden and violent combustion in a spark ignition engine. For this measurement, a standard scale has been devised by assigning the value zero to heptane (C_7H_{16}) which has very poor knock resistance, and 100 to octane (C_8H_{18}) having a very high knock resistance. Octane number is the percentage of this isomer of octane in its mixture with heptane.

Paramagnetic materials These concentrate the magnetic flux by a factor of more than 1 but less than or equal to 10 compared to vacuum, the magnetic permeability of which is taken as the unit value.

Pascal Pascal or 'Pa' is a unit for denoting compressive strength, and is equal to N/m^2. One mega-Pa is 10^6 Pa.

Pellets When very fine particles (size in microns) are formed into spherical objects called 'pellets', the process is called pelletization.

Permanent magnets Once magnetized, these magnets retain their magnetic field indefinitely even after the magnetizing field is withdrawn. These are also called *hard magnets*.

Permeability, coefficient of The common method for measuring it is by Darcy's Law. According to it the coefficient of permeability is measured by the following formula:

$$K = V/I$$

where 'K' is the coefficient of permeability in gallons per day per square foot, 'V' is the velocity of flow of water in feet per day and 'I' is the hydraulic gradient of the medium in feet per foot length.

Phosphorescence Atoms of some luminescent materials stay excited for some time before they de-excite and consequently, they glow in the dark long after they have received extra energy. They are called phosphorescent.

Photoconductivity It denotes the change in the electrical conductivity of a substance as a result of absorbing electromagnetic radiation.

Photoelectric emission When electrons present in the crystal lattices on the surface of a metal are liberated by the addition of energy in the form of light rays, the phenomenon is called photoelectric emission.

Photoemission It is the ability of emitting electrons when subjected to electromagnetic radiation such as X-rays, light etc.

pH value It is the short form of 'potential of hydrogen'. It is the negative logarithm of the effective hydrogen-ion concentration or hydrogen ion activity in gram equivalent per litre. It is used in expressing both acidity and alkalinity on a scale whose values run from 0 to 14 with 7 representing neutrality. Numbers less than 7 indicate increasing acidity and those greater than 7 increasing alkalinity.

Piezoelectricity or electrostriction Piezoelectric crystals can change mechanical strains into electrical impulses and vice versa. The efficiency of transfer of energy back and forth between strain and motion is expressed by 'Q' factor which is defined as the ratio of energy stored to energy dissipated. The higher the Q, the lower will be the energy losses.

Pigment Pigments serve various functions such as acting as fillers, stabilizing binders, protecting against ultraviolet light, reinforcing, controlling thermal expansion, controlling thixotropy, controlling shrinkage, colouring and beautification. There are four types of pigments: (i) pigment extenders, (ii) white hiding, (iii) inorganic and organic colours, and (iv) carbon black.

Poisson's ratio This is closely related to both compressive and tensile strengths. When a bar is pulled or compressed, not only its length alters but also the transverse dimension. Now, for a given material, the ratio between transverse and longitudinal strains has been found to be more or less constant and this ratio is called *Poisson's ratio*.

Polarization Polarization is the process by which hydrogen gas liberated in a chemical reaction goes towards carbon anode and accumulates around it.

Polymerization Polymerization is spontaneous alteration of substances.

Positive temperature coefficient of resistivity or PTC It is the increase in resistivity with increase in temperature.

Powder metallurgy Powder metallurgy is the process whereby many small components are produced by fabricating metal powders or metal and ceramic powders together.

Proppant Proppants are materials which are used for filling up the fracture cavities to prevent closure of oil wells, but without reducing the permeability of the reservoir rock, so that flow of oil or gas can be sustained.

Pyroelectricity and thermoelectricity Pyroelectricity is the ability of certain materials to generate temporary voltage when they are heated or cooled. It is different from thermoelectricity inasmuch as in the former case the whole crystal is changed from one temperature to another whereas in the latter case, one side of the crystal is kept at a temperature different from the other side and the voltage across the crystal is permanent.

Radioactivity Radioactivity is the spontaneous disintegration of certain heavy elements accompanied by the emission of high energy radiation, which consists of three kinds of rays: 'alpha particles', 'beta particles' and 'gamma rays'.

Reducibility Reducibility is a measure of acceleration in the reduction process with increase in temperature in a scale of 0–1.

Reforming Reforming is a special type of cracking in which heavy low-octane naphtha is processed for octane improvement rather than for volatility change.

Refractory Refractory materials are defined as those resistant to heat and having a melting temperature of not less than 1,580 °C. The function of refractory lining is not only to withstand high temperature, but also to resist temperature fluctuation, slag and metal penetration, abrasion, and erosion by hot gases and molten slag and metal.

Rheology It is the study of deformation and flow of matter under the influence of applied stress.

Rupture modulus This is the resistance of a rock slab to bending or flexure. The stress may first cause elastic deformation, then plastic deformation, and finally rupture. In case of brittle objects, there will be no plastic deformation and the object will break as soon as the elastic limit is crossed. Modulus of rupture is expressed in terms of psi or kg/cm^2 of the bending stress under which an object breaks.

Sand According to the definition of the American Society of Testing Materials (ASTM), sand is naturally occurring unconsolidated or poorly consolidated rock particles ranging in size from 0.074 to 4.75 mm, and gravel is similar rock ranging in size from 4.75 to 76.2 mm. But according to many sedimentary petrologists, sand is an unconsolidated granular material coarser than 1/16th of a millimetre and finer than 2 mm (cf. granular gravels are of 2–4 mm size and gravels, more than 4 mm).

Sealant A sealant is an organic substance soft enough to pour or extrude into an opening in an object, and capable of subsequent hardening to form a permanent bond with the object.

Semiconductor These are materials with resistivity intermediate between metals (resistivity $<10^{-4}$ Ω-m) and insulators (resistivity $>10^{3}$ Ω-m).

Shearing strength This is the resistance to tangential force. It is also called *rigidity*. In other words, a body is said to be in shear when it is subjected to a pair of equal forces which are opposite in direction and which act along parallel planes. Shearing strength is expressed in psi or kg/cm^2.

Sialon ceramics It is an advance material comprising a mixture of silicon, aluminium, oxygen, and nitrogen (i.e. Si-Al-O-N). Sialon is suitable for applications requiring high mechanical strength at elevated temperatures, high specific strength (for weight saving without sacrificing strength), high hardness and toughness values, low coefficient of friction and good thermal shock resistance.

Sinter By application of just enough heat to fuse the corners of ore particles, they are made to join together to form a lumpy mass. This product is called 'sinter'.

Soft magnets These can be magnetized easily, for example by electric current travelling in an electric coil wrapped around a soft magnetic core, but they lose their magnetism once the current is turned off.

Soldering It is the process of joining two metal pieces by welding with an alloy of tin and lead called solder.

Spallation It is the process in which detachment of a large number of neutrons from the nuclides of some high-atomic number element is caused by its collision with protons which are accelerated to high energy in an accelerator.

Specific heat Specific heat of a substance is the ratio of the amount of heat required to raise the temperature of 1 g of it by 1 °C to that required to raise the temperature of 1 g of water by 1 °C.

Surfactant It is the acronym of 'surface active agent', and it removes dirt from a soiled surface by attracting the dirt particle to its surface by ion exchange.

Taconite Taconite is the name given to fine-grained compact siliceous iron formations—ferruginous chert or ferruginous slate containing very finely disseminated oxides of iron, less than 20 mesh in size.

Tensile strength It is also called resistance to longitudinal stress, because this kind of stress tends to produce unidirectional change in a body. Tensile strength of rocks is expressed as pounds per square inch (psi) or kg/cm^2.

Thermionic emission When electrons present in the crystal lattices on the surface of a metal are liberated by the addition of energy, in the form of heat, the phenomenon is called thermionic emission.

Thermoelectricity *See* 'Pyroelectricity'.

Thixotropy It is the property of pseudoplastic fluids showing time-dependent change in viscosity. Longer the shear stress, lower is the viscosity (e.g., ketchup, some clays, gels).

Toughness Also called impact toughness, it is the resistance to sudden impact and is expressed in inches (height of the fall) per square inches.

Transducer It is a device by means of which energy can flow from one transmission system to another.

Value of colour The value indicates degree of lightness or darkness of a colour and it is related to both the percentage of light reflectance and the degree of lustre. Obviously, pure black has the lowest value and pure white has the highest value.

Viscosity Viscosity is that property of a liquid which is a measure of its internal resistance to motion and which is manifested by its resistance to flow.

Water footprint Water footprint of the people of an area is an index for indicating the consumption of water. It is the total amount of water consumed by the people of an area that is used to produce goods and services consumed by the inhabitants of that area.

Welding Welding is a metal-joining process wherein coalescence is produced by heating to suitable temperature with or without pressure and with or without the use of filler metal.

Yield point It is the point where a stressed material no longer deforms elastically, but begins to deform permanently. Its unit of measurement is lb/in^2 or kg/cm^2.

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