World Energy:

The Past and Possible Futures

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World Energy: The Past and Possible Futures

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PREFACE

This is the second edition of *World Energy: The Past and Possible Futures.* The first edition was published in March 2005. The basic structure of this publication has undergone few changes in comparison to the previous edition. The world energy situation and markets, however, have experienced many changes since March 2005. Fossil fuel prices, in general, have significantly increased. While the oil price benchmark spot West Texas Intermediate (WTI) averaged US$54.19 per barrel in March 2005, it averaged US$72.36 in August 2007 and climbed above US$80 in mid-September. Fossil fuel based electricity generation is becoming increasingly more costly and concerns over global warming and CO_2 emissions are gaining further momentum in world public opinion. These have led to a resurrection of interest in relatively more economical and cleaner electricity generation sources such as wind and nuclear power.

Energy has been and remains an essential element of human evolution and progress. To attain a sustainable future, we must not only achieve efficiency in using global resources but also ensure that the capacity of the biosphere to absorb residual products and waste from our activities is not breached. Many believe that this requires significant and immediate changes to how we produce and use energy. Without such change, the path we are on, in this view, could lead to social and economic conflict and irreversible environmental damage.

This study brings together the work of many commentators on energy and the environment to provide a summary of the relevant past and a way to look at the possible future. We have drawn liberally from previous work within the Canadian Energy Research Institute (CERI); adapted the presentations of others, such as BP's *Annual Review of Energy* and the works of the International Energy Agency and the US Energy Information Administration; and drawn from the *World Energy Assessment,* a joint review of the United Nations Development Programme, the United Nations Department of Economic and Social Affairs, and the World Energy Council. Thus, we have not attempted to provide purely original interpretations of the past or the likely future. However, we have attempted to mine the existing information in a selective way that, we hope, will prove useful to readers in considering the important issues raised here. While we acknowledge the excellent work done by all of the sources upon which we have drawn, we retain full responsibility for any errors, omissions, or misinterpretations in the present work.

We would like to thank the members and sponsors of CERI's research program for making this work possible. Special thanks go to the National Round Table on the Environment and the Economy for their support of previous work that has been used selectively here and to the Canadian Nuclear Association for financial and moral support in our pursuit of an objective overview of the energy sector and its implications for the environment.

The Authors

The authors of this new edition, which draws heavily on the previous edition, would like to begin by acknowledging and appreciating the contributions of the previous edition's authors. The following people contributed to this new edition.

Mr. Marwan Masri was appointed President and CEO, Canadian Energy Research Institute (CERI), in August 2007. Prior to this appointment, he served as Vice President Research at CERI from late 2005 to July 2007. Previously, Mr. Masri had worked with the California Energy Commission in Sacramento, California for 29 years. As Director of their Renewable Energy Program, he led a special team of consultants that worked toward the design and implementation of a $1.9 billion program transitioning independently-owned renewable power projects into the competitive market. This program, implemented in 1998, earned national and international recognition. Other previous positions include: Senior Economist, Energy Analyst, Energy Siting Planner, Solar Energy Specialist, Energy Economics/Statistics Specialist, Energy Fuels Specialist, Energy Commission Supervisor II and Deputy Director, Technology Systems Division (R&D).

Dr. J.P. (Phil) Prince was appointed President Emeritus, CERI, in August 2007. From April 1999 to July 2007, he was CERI President and CEO. Prior to his appointment to CERI, he served as a Board Member for the Alberta Energy and Utilities Board and as co-Chairman of the Energy Resources Conservation Board. Phil's previous experience spans 25 years in various roles associated with the energy sector. In 1985, he received the Robert Elver Mineral Economics Award, presented by the Canadian Institute of Mining and Metallurgy.

Dr. Seyed Jazayeri was appointed as Senior Research Director, CERI in October 2005. Prior to his appointment to CERI, he served as Models and Forecasting Coordinator at the secretariat of the Organization of Petroleum Exporting Countries (OPEC) in Vienna, Austria for eight years. There he was charged with the development of mathematical and econometric models, and involved in the forecasting of oil market fundamentals. During the 1990s, prior to joining OPEC, Seyed worked as a faculty member and Deputy Dean of the College of Accounting and Finance at Iran's Petroleum University of Technology. For 10 years, Seyed reported to Iran's Deputy Petroleum Minister and President of the National Petrochemical Company (NPC) as General Manager of NPC's International Affairs Department.

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EXECUTIVE SUMMARY

As noted in the **Preface**, we have prepared an annotated survey compiled from varied sources of commentary on energy, environment, and the economy. We did not set out to provide new insights into these relationships; rather, our purpose was to bring together some views we have found useful, to emphasize some points of importance, and to make the general discussion available to a broad and, possibly new, audience. Because this is a survey, the scope for summary is limited.

Nonetheless, we provide here an overview of each chapter as well as a concluding commentary on the possible evolution of the energy sector.

Chapter 1 — Introduction highlights the historical evolution of energy sources, as technological advances changed how energy assists human activity. We then set out a simple depiction of economic activity, with energy as an input to the economic process in a world where there are no environmental limits. This unlimited view of the world was common until very recently, when issues of waste, pollution, and climate became broadly acknowledged. Next, we depict a new view of the world — one where the capacity for waste absorption has limits. These limits necessitate both theoretical and policy assessments which differ from those reflecting the simple world that was previously assumed. And, finally, we provide some broad lessons from a relevant piece of research in the literature, summarized in three main points:

- the study of historical trends has some use, given that global and national economies, like huge ships, only change direction slowly and with great effort;
- nonetheless, technological change provides an unavoidable source of uncertainty that can frustrate our attempts to forecast the future; and
- finally, over very long time periods, some changes are simply unforeseeable, regardless of the skill and resources used to try to discover them.

Chapter 2 — World Energy Outlook sets out a particularly useful approach for understanding possible futures. After discussing some of the basic variables that will affect future energy use, with some emphasis on population and energy intensity, we summarize two of the most useful sets of scenarios in the recent literature, taken from the International Energy Agency's (IEA) 2003 publication, *Energy to 2050: Scenarios for a Sustainable Future* and the 2006 publication, *Energy Technology Perspectives 2006: Scenarios and Strategies to 2050*. We like these scenarios because they incorporate clearly and simply the main drivers of future energy use and illustrate the major uncertainties in an objective way.[1] The depiction of these scenarios in generalized graphs, with technological change on the vertical axis and attitudes toward the global climate on the horizontal axis, enables readers to grasp easily the implications of the scenarios.

The study of historical trends has some use, given that global and national economies, like huge ships, only change direction slowly and with great effort.

For example, the "clean but not sparkling" scenario emphasizes allocating today's resources to reducing unwanted emissions into the atmosphere. That approach reduces the likelihood of future adverse impacts on climate from the greenhouse effect. However, it also reduces the amount of resources directed at research, thus inhibiting technological advance. Since advancing technology may be the most effective way to reduce total emissions over longer time periods, the world could ultimately be worse off in the scenario that focuses on cleaning the air today at the expense of research into technology. Another approach, the "dynamic but

[1] The IEA 2003 publication includes a normative or subjective scenario to provide guidance toward a sustainable future. While we strongly recommend this to interested readers, it is not our purpose to be prescriptive and so we did not include it here.

careless" scenario, fosters technology but has little concern for the global environment. Such an approach might take us beyond a point where remedial action is possible, condemning future generations to a lower-quality environment or worse. While there is great uncertainty associated with such arguments, the scenario approach enables a wider audience to appreciate those uncertainties and to understand the potential trade-offs that are implicit in various approaches to the problem. The essential point of the discussion is that technology and concern for the environment are linked, and sustainable development may require appropriate emphasis on both.

Chapter 3 — Historical Energy Consumption focuses on energy use over time, both trends and the factors that cause them. At a global level, the main drivers of energy consumption have been population growth, economic growth, and energy intensity.[2] These are discussed in some depth. Global energy use has historically, and quite logically, increased as population and economic activity have increased. Energy intensity has declined over time in industrialized nations, reflecting increased efficiency and a shift toward services. As developing countries progress economically, a similar pattern is beginning to emerge. Currently, Central and Eastern Europe exhibit the highest energy intensities, likely a result of social and political organization and pricing that is not determined in free markets.

At a global level, the consumption of energy has increased over time and will increase in the future to support increasing populations and increasing economic activity. The growth in energy use may be slowed, but not stopped, by greater efficiency. The needs of developing economies ensure that growth in total energy consumption will continue. The pattern of energy use, however, differs by source. As discussed in the next chapter, fossil fuels as a group continue to provide the bulk of primary energy supply. But with the increasing importance of electricity in economic activity, and a growing environmental consciousness, other sources of supply may be developed. Alternative sources of energy with no emissions, such as wind and solar, will be more desirable. Nuclear power, also with negligible emissions to the atmosphere, is likely to be increasingly accepted over time. The perceived problems with nuclear power can be resolved, and the environmental benefits appear to be growing in importance. The consumption chapter concludes with a comment on the possible future, set out below.

At a global level, the main drivers of energy consumption have been population growth, economic growth, and energy intensity.

We do not, in general, desire energy for its own sake; we desire it for the services it provides: heat, cooling, power, light — all the things that make our lives easier. That means the ultimate mix of energy sources that emerges is only partly dependent on the form of that energy. Transportation needs will keep oil in demand through the middle of the century, because alternatives are not likely to emerge on a large scale before then. Natural gas will grow in importance because we have an associated demand for lower emissions, and gas is a cleaner-burning fuel. That characteristic may boost our interest in nuclear as well, particularly as knowledge about the real risks and costs of that source becomes more widely disseminated. Renewable sources of energy are desired, but in the past their use has been limited by a lack of willingness to pay the needed premium for them. The ultimate desired mix of energy sources will depend to some extent on how consumers value the services of energy compared with the services of the environment.

Chapter 4 — Historical Energy Supply describes how energy supply has evolved. Historically, biomass in the form of wood and other combustible vegetation was the major source of energy. As technology changed, coal use became prevalent, later to be displaced by oil. Currently, natural gas is the fastest growing energy source. As electricity became integral to modern living, hydroelectric and nuclear energy

[2] Energy intensity is an overall measure of efficiency defined as the amount of energy needed to produce one dollar of economic activity.

became more important (though relatively small as a percentage of total energy supply). As we look to the future it is clear, as set out in Chapter 4, that we do not face an imminent supply constraint on a global level. The reserves of hydrocarbon-based sources of energy are adequate to ensure supply through to 2050 (and for coal, much longer). Crude oil will maintain its dominance in transportation but slowly give way to natural gas in other uses because of that fuel's lower emissions. Coal, with its opposing characteristics of high emissions but low relative price, will maintain its position, and will grow when the environmental issues have been resolved. The problems associated with fossil fuels are not immediately problems of adequacy; rather, they are problems of location. The resources are not located where they are needed. Therefore, issues of transportation and security will take on added importance in the early part of the century. While the problems associated with moving oil are well known and have been accommodated, natural gas will inevitably become a globally-traded commodity as well, giving rise to a large fleet of tankers and port facilities to handle liquefied natural gas (LNG). In the early years of the 21st century, the problems of siting such facilities may become a significant hindrance to the efficient evolution of trade. Hydroelectricity and nuclear power —

The existing stock of capital dedicated to providing and using energy is, after all, like a huge ship on a calm sea: it takes time and effort to turn it around.

with similar environmental advantages and some adverse perceptions based on costs, safety, and other environmental impacts — will see a resurgence of interest as understanding grows and the environmental imperative becomes more apparent. Renewable sources of energy such as wind, solar, geothermal and marine, will take hold gradually, barring a significant technological breakthrough. The existing stock of capital dedicated to providing and using energy is, after all, like a huge ship on a calm sea: it takes time and effort to turn it around. The increasing importance of environmental considerations in relation to the likely or most desirable mix of energy sources is gradually being recognized. This suggests the importance of pursuing appropriate technological innovation so that we use our existing supplies effectively and find new sources of energy that meet the needs of humanity while minimizing impact on the environment.

Chapter 5 — Energy and the Environment is concerned with broad questions of sustainability. From a supply perspective, sustainability refers to the reserves of primary energy sources and how long they are likely to last. Since energy use involves waste products, another dimension of sustainability is how long "spaceship earth" can effectively shield against the waste products from energy use. We start with the supply question, reviewing first the basic fossil fuels: oil, gas, and coal. Oil and gas in particular are clearly adequate to carry us through the first half of this century, and quite likely well beyond that, into the next century.[3] This supply would come at increasingly higher cost, of course, and with potential geopolitical friction; but for our purposes here, relative security for a century is adequate to put the question aside. As the pressure on fossil fuels grows, and their prices move ever higher, other sources of energy will become more attractive. These include large and small

[3] Coal resources could last much longer given their vastness and relatively even distribution around the world.

hydro, nuclear fission, nuclear fusion, biomass, wind, solar, geothermal, marine, and hydrogen. The issue of waste relates to solids, liquids, and gases, all of which are associated with the provision of energy. Some gaseous emissions with toxic effects on humans, referred to as critical air contaminants, have been directly controlled in many jurisdictions. However, over the long term, the capacity of the atmosphere to accept emissions without triggering adverse climate change is a major concern. Thus attention has been focused on greenhouse gases and their effects.

The main greenhouse gases include, in order of importance: water vapour, carbon dioxide, methane and nitrous oxide, as well as many others of much smaller volumetric importance. The primary human contribution to greenhouse gases comes from carbon dioxide through combustion.[4]

The greenhouse effect refers to the belief that certain gases enhance the thermal blanketing effect of the atmosphere, thus raising temperatures on earth higher than would otherwise be the case. This has allowed life to evolve; however, if the warming effect continues to increase, the earth's climate could change in somewhat unpredictable ways. Some regions could see relative improvements, others, deterioration. On balance, the overall global impact is likely to be adverse. Thus there have been ongoing attempts to measure the concentration of carbon dioxide in the atmosphere over many years. These have concluded that over a period of 150 years, concentrations have increased by almost 30 percent. Although sinks such as oceans, forests and soils remove carbon dioxide, the cycle is very long — approximately 100 years. Thus global warming remains a concern. Regionally, Africa and Central and South America had much lower emissions than the rest of the world in the year 2004. Fuel, coal and oil contribute roughly 40 percent each to total emissions, whereas natural gas contributes about 20 percent.

The combination of dwindling supplies of fossil fuels and concerns about greenhouse gases naturally leads to the consideration of other forms of energy. Large hydro power has considerable potential in some areas of the world, whereas in others the remaining possible sites are limited. The massive impact of large hydro on the local environment has also generated opposition in spite of its low emissions (not zero because of decaying vegetation associated with most developments). Smaller run-of-the-river hydro has less impact and negligible emissions, thus its potential is high in many parts of the world. Nuclear fission has been stalled for many years because of fears related to safety, waste handling, proliferation, and high costs. These fears are partly attributable to lack of public understanding, but the issues must nevertheless be addressed. Because nuclear waste remains active for long periods of time, the fears are multiplied in the minds of the public. However, as the importance of global warming gains acceptance, and the issues related to nuclear power are addressed, a nuclear solution becomes more acceptable as well. Biomass accounts for 10 percent of current world supplies, but that increases to 22 percent in the developing countries and to as high as 49 percent in Africa. While biomass use without replacement generates greenhouse gases, there are ways to use it more efficiently. Biomass is a renewable source of energy and, therefore, remains important.

Wind, solar, geothermal, and marine sources of energy are often referred to as "new" renewables. Collectively, they provide close to 1 percent of total primary energy supplies.

Wind, solar, geothermal, and marine sources of energy are often referred to as "new" renewables. Collectively, they provide close to 1 percent of total primary energy supplies; however, some of them have been growing at very high rates over the past 20 years. Various applications of each of these largely emission-free sources can be found in some stage of development or commercialization around the world. Wind

[4] However, there is a secondary effect as well, since warming increases evaporation, thus adding to the most significant GHG, water vapour.

energy has been the fastest growing, particularly in Western Europe, and is now being more rapidly introduced into other regions as well. All of these sources continue to be subjects of research and development, with promise for the future. However, given their very small base today, they have limited ability to make a significant impact on the overall energy scene. As a result, it will likely be several decades before wind energy becomes a major component in energy supply relative to fossil fuels.

Hydrogen is an even more distant prospect, though it is also highly attractive should the technology and associated infrastructure emerge. Hydrogen is abundant everywhere on the earth's surface, and its combustion produces no harmful emissions, only water and heat. Currently, the costs of production are excessive. Even if that issue is resolved, an extensive distribution system will still need to be developed. Although many countries are involved in research, extensive commercial application that could lead to the so-called hydrogen economy is several decades, if not further, into the future.

The primary human contribution to greenhouse gases comes from carbon dioxide through combustion.

In summary, alternative energy sources are gaining support because of concerns about global climate, evidenced in the ratification of the Kyoto Accord. These sources represent a potential answer to long-term energy requirements and would also help to reduce the effect of energy use on global climate. Even though scientific and technological advances have an element of serendipity to them, it does not seem likely that major breakthroughs will be seen before the latter half of this century and perhaps not until the next century.

Chapter 6 — North American Energy Outlook and Issues takes a turn to the regional energy issues that have emerged in North America in recent years. These include the inevitable growth in energy demand combined with the likelihood that conventional supplies of fossil fuels will plateau and eventually diminish. The associated upward pressure on energy prices has implications for all economic activity. There is a long-term need to achieve sustainable energy from the point of view of both supply and the associated effects on climate.

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The following chapter addresses concerns regarding fuel for each of the three North American countries: Canada, the United States and Mexico. While each country has its own pattern of energy use, they all face the same broad issues of sustainability. Growing demand and slowing supply have led to increases in prices that in turn have had broad effects throughout each economy. The oil market is globally based, and prices in North America follow those in world markets. Natural gas, on the other hand, is still a regional market, with prices set at various places on the continent and with a rough equilibrium emerging

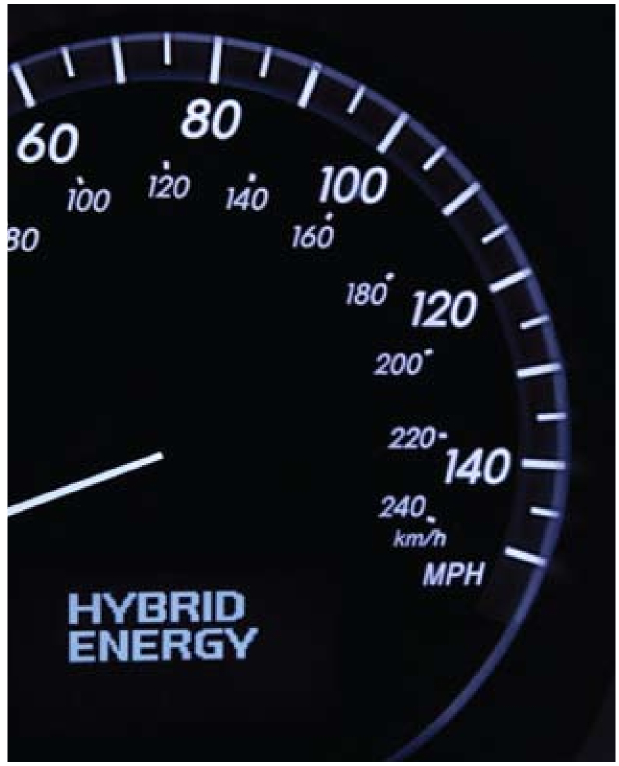
over time.[5] The lessons learned in earlier decades about the futility of interfering directly with markets to affect pricing continue to be observed.

The main issues in Canada and the United States relate to maintaining supplies of fossil fuels and facilitating the infrastructure needed to deliver them from supply regions to markets. Mexico is also concerned with ensuring that its resources are domestically developed, an objective that is somewhat at odds with rapid, efficient exploitation of its resource base. Large hydro development has been the most extensive in Canada; however, the available sites for future development are limited. Coal is used relatively more in the United States, with associated environmental issues. Nuclear energy, in all three countries, seems on the verge of becoming more broadly accepted. In Canada, nuclear power accounted for some 15 percent of electricity generation in 2005. The figures for the United States and Mexico are close to 19 percent and less than 5 percent, respectively. Canada is also the world's largest producer of uranium, accounting for almost 30 percent of total world production.

Chapter 7 — Will Energy Efficiency Improvements Alter the Balance? We identify two main ways to reduce energy consumption, though most people view them as the same thing — conservation. The two ways are (1) use less energy and (2) use energy more efficiently. While there are clear differences in the approaches, we choose, in this brief discussion, to combine them.

The simplest approach to using less energy is through personal decisions: walk or bike instead of driving, put on sweaters instead of raising the thermostat, etc. These decisions can be facilitated, for example, by designing communities to encourage walking. However, such decisions require significant buy-in on the part of the public in order to produce a noticeable impact on total consumption. Western society does not appear to have adopted the requisite attitudes yet.

Increasing the efficiency with which we use energy also requires public support. More efficient light bulbs have been available for many years but have not enjoyed



mass acceptance. Many investments that are economically sound do not provide a quick enough pay-off for most consumers, even though they do provide a healthy return on the investment. For example, a high-efficiency furnace pays back its extra costs over roughly five years, after which it generates ongoing savings. Nonetheless, many consumers are not willing to make the required initial investment.

The situation is complicated by restructuring in the electricity sector. Prior to that, many utilities had some success with demand-side management programs that were intended to provide incentives for people to consume electricity outside peak hours. This not only saved operating costs in some situations, but it also deferred the need for new investment. However, such results are hard to measure and have been viewed as mixed. After industry restructuring, no single entity has an incentive to try to reduce, or shift, consumption patterns. However, there is still a potential incentive that may come into play through the pricing system. Until now, that incentive has been hindered by the fact that individual consumers, at least at the residential and commercial levels, do not see the real-time price and cannot, therefore, be expected to change their behaviour because of price changes (as is common

5 This is being changed as LNG becomes more widely traded.

in most markets). This constraint has led to other experiments related to pricing, and some of these have enjoyed limited success. The potential rewards appear to be large. It has been estimated that 40 percent of the growth in peak demand could be avoided through effective efficiency improvements.

Residential and commercial gains usually depend on education programs and targeted subsidies for certain things, such as better insulation.

Effective ways to achieve efficiency can differ between the residential, commercial, and industrial markets. Residential and commercial gains usually depend on education programs and targeted subsidies for certain things, such as better insulation. There are also initiatives such as labelling appliances with an efficiency rating. Industrial efficiencies are somewhat easier to realize, in part because they are larger entities in smaller numbers. Programs can be defined for specific industries, requirements can be made mandatory, and, most importantly, time-of-use metering can be used to promote individual plant behaviour that is rational and saves energy while lowering costs to the plant. In certain sectors, such as transportation, there is a large potential for improvement by adapting new technologies at the manufacturing level; as these become accepted in the market, they become less expensive to produce, presumably resulting in a friendly cycle of improvement.

Chapter 8 — The Special Case of North American Electricity is a short discussion of the evolving electricity market in North America. We include this chapter mainly as a flag to readers that the attempt to restructure this essential industry is both a source of many current problems and much future opportunity. Because parts of this market are natural monopolies, the restructuring has focused on generation and retail choice. However, with some components of the market remaining under regulatory oversight, the electricity marketplace is more complex than others, and individuals have more difficulty understanding how to make advantageous decisions. Until the markets can achieve the desired structures that allow real-time prices to affect the decisions of consumers, restructuring is not likely to achieve unqualified success. This means issues such as market power, reliability and price volatility must be resolved by an acceptable market design. When that happens, there may be a significant contribution to energy efficiency.

The overview concludes with three short appendices, a glossary of terms, and a bibliography. The appendices provide brief comments on: (1) the oil refining sector in North America; (2) the natural gas pipeline infrastructure; and (3) conversion factors. These are essentially intended to show that much complexity has been omitted by our approach to the review. We hope the reader will find it useful to examine the bibliography, which goes beyond what has been cited in the text and covers much interesting work that has come to our attention in recent years.

Summary Comments

Energy is integral to economic activity and to enhanced standards of living for the human population of planet Earth. Over history, the sources of energy have adapted to the needs of the age, depending on the level of technological development at the time. More recently, it has been recognized that the use of energy has by-products that may affect the environment, in particular the global climate, and could eventually threaten human existence.

At a geopolitical level, energy resources have altered wealth relationships among countries and provided an impetus for development that has aided many nations in improving their economies. Currently, fossil fuels provide most of the primary energy used on the planet. However, they are problematic with respect to emissions and the potential to adversely affect future climate. Moreover, they are finite and some appear to be on the verge of decline.

This leads to consideration of alternative sources of energy that may be developed for the use of future generations. Although these alternative sources may not be significant now, their advantages suggest they will take centre stage either sometime this century or early in the next century. Wind, solar, marine, and geothermal, all sources that have little effect on climate, are among the future stars. Nuclear energy seems poised to capture a level of acceptance that it has not known for decades. Nuclear may also be a key to the transition to a hydrogen economy, the promise of which is a sustainable energy source with no environmental impacts.

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The path that is taken toward future realities will determine how well we provide for future generations. We believe that an adequate — meaning much increased — commitment to research in science, technology and policy will be necessary to find the best path forward.

1 INTRODUCTION

The following review looks at human uses of energy to enhance lives. That short sentence of intent implies a potentially enormous study, since energy has been central to human existence and development from pre-history to the present. We have chosen to contribute to the non-specialist's understanding of the evolution of the production and consumption of energy evolutions. We also seek to impart some sense of understanding about the issues that will condition the future collective use of energy and the complexities that make the actual outcome impossible to predict.

The compelling motion picture *2001: A Space Odyssey* begins with a dramatization of how man was differentiated from other animals early on; namely, in the understanding of tools — the use of a club to aid in combat and the harnessing of fire. Over a long stretch of history, advancements in both technology and the sources of energy to support it have contributed to economic development. Such development has also been redirected by changes in technology or available energy. An example from the 16th century is the once-thriving iron-making industry in England. Shortages of wood eventually restricted the capacity to make charcoal, causing the industry to shift from England, first to Ireland and later to Scotland, to access abundant supplies of wood.[6]

Over a long stretch of history, advancements in both technology and the sources of energy to support it have contributed to economic development.

Later still, in the 19th century, charcoal succumbed to coal, and in the 20th century coal faced significant displacement from many uses by oil. Today, oil is under pressure from natural gas. Many hope and believe that renewable sources of energy will soon largely displace

[6] Auke Koopmans, "Trends in Energy Use," paper presented to the Expert Consultation on Wood Energy, Climate and Health, Phuket, Thailand, October 1999.

fossil fuels, although most recognize that would take a significant policy stimulus through subsidies. The long-term energy future might well be hydrogen based — potentially clean but currently costing more energy to produce than it provides. And many believe that nuclear fusion — safe, limitless, and clean — will eventually make a major contribution to energy supplies, although technology is not likely to reveal a path to it for many decades, if not longer.

And so it goes. Looking back on these changes it is possible to see what led to them and to trace their impact. But looking forward is a different matter. Forecasting is now recognized as a sometimes necesary, always difficult, activity that is most useful as a way to discuss possibilities. Here we describe the past and adapt some simple scenarios to describe possible futures.

1.1 Interaction of the Economy and Energy

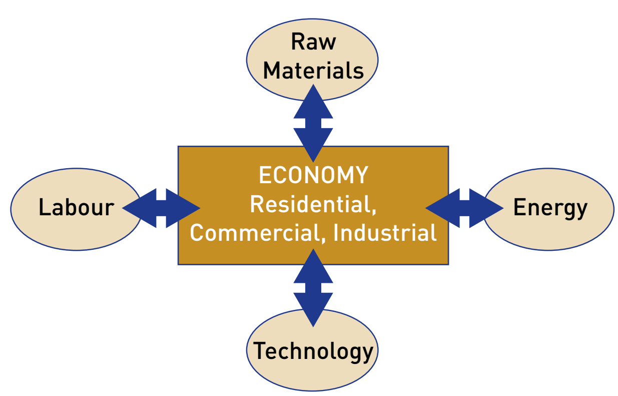
From an economic viewpoint, energy is one among many factors necessary to produce goods and services. Human labour, raw materials, and productive machinery are other factors of production. Technological advancement has been important in allowing us to use energy more effectively to get what we want. Access to energy is vital in enabling technology to play its role. It has been a very friendly circle, indeed. In primitive societies, oxen pulled simple tools to assist in agriculture. Today, one person in a single modern tractor — sitting in air-conditioned comfort with music on the CD player — can do the work of hundreds of oxen and people.

The world is not, however, a single community where everyone benefits from such progress. Those in developed economies have access to the fruits of scientific and organizational advances.[7] But there are many developing countries in the world today that for various reasons have not matched the technological evolution of the developed world and who do not, as yet, share in the resulting bounty. In these developing countries, less access to energy is common. There are some two billion people, one-third of the world's population, who do not have access to electricity in their homes. While there are slow but continuing improvements, one of the challenges of the modern world is how to enhance the lives of the less fortunate. Nonetheless, even developing populations have seen some benefit from technological progress, and for the lucky residents of the developed world, their work has been made much easier and has altered in nature because of technological advancement and the availability of usable energy. This has made life easier, longer, and more comfortable for those with access.

The preceding discussion glosses over the complexities of the relationships involved even in one region or country, let alone the entire world. Figure 1.1 below sets out the broad relationships, omitting the details of the interactions.

Even in a much-simplified model of economic activity, describing the sectors of the economy and relating them to each other takes literally thousands of equations, as we are defining relationships that must regularly be estimated through econometric approximations. To capture changing technologies and other efficiencies is an almost impossible task. Nonetheless, we use such models for the rigorous description and attention they require from us, and because the back of the envelope simply does not suffice for many problems. Modellers must, therefore, run their equations, most of which have judgments embedded in them, to give us pictures of possible futures. Then they run them again, changing critical things, and we get other possible outcomes. This process is extremely useful if proper care is used to interpret the results.

Figure 1.1
A Simple Economy: No Constraints



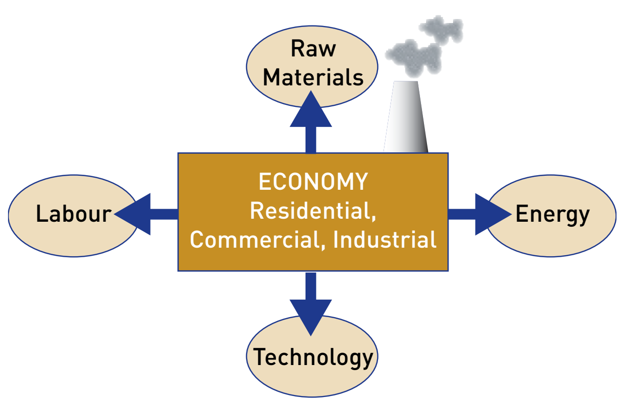
[7] Of course, not everyone in the developed world has the same level of access. Some are richer than others and command greater access to the benefits of modern life.

Unfortunately, the global picture is now complicated by an inevitable development: accumulating waste products. Over the course of history, the earth and its environment have been providers of good things, such as fertile land, energy resources, water, and air, as well as receptors for the residual waste of human activities, both solids and gases. The simplified picture above must add another element, the capacity of the environment to absorb the residue of human activity in the form of solid, liquid and gaseous waste products.

The capacity of the earth to adapt to the results of ever-growing human activity is not infinite. Figure 1.2 illustrates a simple economy that has some limits on what it can absorb from the activities it induces. The smokestack stands in for all the sources of solid, liquid, and gaseous waste that are by-products in modern economies. For most of human history, these limits were effectively non-existent, since our activities were small relative to the capacity of the biosphere. Today, there is increasing concern for future generations about the implications of continuing our ways of doing things. Although solid waste in all its forms, from metals to electronics to plastics, is a growing problem in most regions, gas emissions, in particular greenhouse gases (GHGs), are the more worrisome global issue. This worry stems from the concern that GHGs accumulating in our atmosphere will eventually, through the greenhouse effect, increase the average temperature of the Earth. That increase in temperature will in turn melt the polar icecaps, raise the level of the oceans,

Figure 1.2

A Simple Economy: Limited Waste Absorption Capacity



submerging some coastal areas, and have an unpredictable impact on both short-term weather extremes and long-term climate.

The capacity of the Earth to adapt to the results of ever-growing human activity is not infinite.

To use a heroic simplification, there are two opposing points of view on the issue of climate change. One says that in the worst case, these changes could make our world uninhabitable. Therefore, we should take rapid and strong action to reverse the trend. This includes both individual and national initiatives to reduce our use of energy now, even at some significant economic cost — thus reducing current emissions while we seek effective and permanent solutions.

Others point to our limited understanding of global climate, and question whether there is an imminent danger. They argue that reducing energy use reduces economic activity and has a high cost in terms of forgone investment in technology. Reduced investment in technology limits our ability to respond effectively to climate issues. This group believes we must look to technological development to solve the greater part of the problem and it is important to avoid unnecessary reductions in economic activity. We need to achieve a delicate balance in our response.

A related problem is the prospect that our efforts on the climate front in the developed world may be totally offset by activity in the developing world, where there is reluctance to forgo economic growth while they are still so far behind the rest of the world. That is, in fact, another pressing issue with respect to the global management of resources: equity among nations. This study does not resolve either of those issues, but it may contribute to our understanding of the problems, some contributing factors, and some of the proposed solutions.

1.2 Lessons of History

In 1963, the prestigious think-tank Resources for the Future (RFF), based in Washington, D.C., released an extensive study called *Resources in America's Future.*[8] Some 22 years later one of the authors, Hans H. Landsberg, presented an informal assessment of how the study compared to the unfolding reality.[9] He reported a number of interesting observations, of which we select a few germane to this discussion.

With respect to two fundamental variables, population and economic activity, RFF's estimates were directionally wrong, but offset each other. RFF selected a population forecast for the US that turned out to involve higher than observed rates of growth and by 1980 its estimate of 245 million people was 20 million too high (with the disparity undoubtedly growing through 1990 and 2000). The error stemmed from the fact that for the 15 years prior to its study, annual population growth had been steady in the 1.7–1.8 percent range, but in 1962, as RFF was finalizing its work, the rate began to fall, and by 1968 was about 1 percent. Moreover, the study was influenced by numerous forecasts in past years that had underestimated growth. On the economic side, it projected gross national product (GNP) to grow by 3.8 percent per year, and the actual growth was 3.9 percent per year. Behind that remarkable accuracy were a number of errors that happened to offset each other. For example, RFF failed to get the growth of the labour force right because it did not foresee the increasing participation of females. However, it also missed productivity gains, forecasting a 50 percent

8 Hans H. Landsberg, Leonard L. Fischman and Joseph L. Fisher, *Resources in America's Future: Patterns of Requirements and Availabilities 1960-2000,* published for Resources for the Future by Johns Hopkins University Press, Baltimore, MD, 1963.

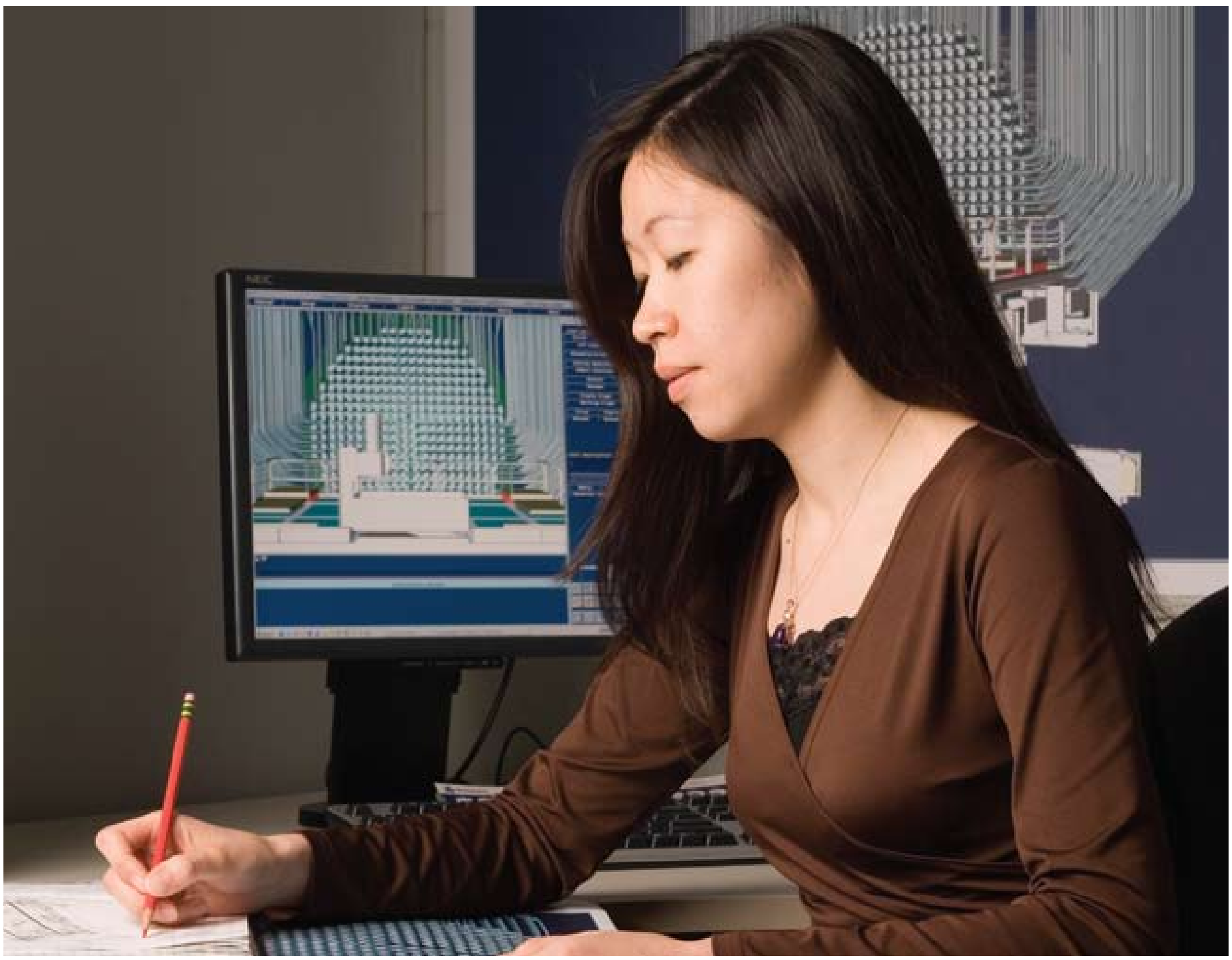
9 Hans H. Landsberg, "Energy in Transition: A View from 1960," *The Energy Journal,* Volume 6, Number 2, April 1985.

increase over the period, with the actual rate being only 40 percent. Thus the net effect of these and other errors was a forecast very close to what occurred.

RFF failed to get the growth of the labour force right because it did not foresee the increasing participation of females.

The result with respect to energy consumption was equally interesting. RFF forecast 1980 energy consumption at 79.2 quadrillion British Thermal Units (Btus), or quads; it turned out to be 79.6 quads. Again, a number of misses offset one another to yield a remarkably accurate 20-year guess. With respect to energy sources, RFF underestimated coal use, overestimated gas use, and was nearly correct on, of all things, oil markets, which were subjected to great changes over the period.[10] A similar result applied to energy use by sector. The result of Landsberg's review was most interesting with respect to the general conclusions he felt able to draw.

- First, he noted that extrapolation of past trends is not necessarily a useless exercise. The past can indeed provide clues to the future. The momentum inherent in a large economy is important in this connection, as is the fact that the capital stock changes only slowly over time. Landsberg noted that although thoughtful extrapolations do not guarantee accuracy, they do make it easier to track the errors



[10] Given the tumultuous events in world oil markets in the 1970s, which could hardly have been foreseen, the result is surprising.

and understand their source, as time passes. We, therefore, spend some effort in what follows to set out the historical record.

- Second, the largest errors were related to technological change, particularly which focused on increasing the efficiency of energy use. One notable example was the case of nuclear power. With little actual production in 1960, and little public antipathy as well, RFF based a robust growth forecast on likely regional cost differentials. This led to a forecast of 400 billion kWh in 1980, some 80 percent higher than was reached. We view technology as one of the most important and hard to forecast variables in looking to the future.
- Third, over long periods of time, measured in decades, events occur that are simply unforeseeable. While this may seem obvious, it is always necessary to predict the future from the platform of the present, and some changes are very hard to foresee.

Twenty years later, virtually all of these questions would be on a current list of major uncertainties.

While Landsberg drew other conclusions, the above three relate directly to our current effort and are most instructive for the current work. Perhaps as interesting, if not more so, is a series of questions that Landsberg identified in 1984 as waiting for answers in the next 20 years. Twenty years later, virtually all of these questions would be on a current list of major uncertainties.

- Will nuclear energy resume its growth? Will there be breakthroughs on the breeder reactor and on fusion?
- Will solid-to-gas and solid-to-liquid conversion become commercially viable? For coal? For shale? If so, when?
- Will solar energy make inroads or continue to serve only specialized markets?
- Has the price of crude oil shifted upward to a new price-band for the near-term future? Or will we again see major price fluctuations?
- Will the price of oil resume its upward movement? If so, how soon?
- Will the developing countries put increasing pressure on energy supplies? If so, how soon?
- When and at what cost will we have clean-burning coal?
- Will the efficiency of the US automobile climb above the government-mandated 27.5 mpg? How far and how soon?

The rest of this report comprises seven chapters. **Chapter 2** lays out a scenario-based view of the world energy outlook. **Chapters 3** and **4** present analyses of past trends in energy demand and energy supply. **Chapter 5** is concerned with the relationship between energy use and the environment. The chapter presents a discussion of energy sources that are potentially sustainable. North America's energy outlook is described in **Chapter 6**. **Chapter 7** is concerned with the possibility of improvements in energy efficiency as a means to reduce the need for energy. The special case of North American electricity is discussed in **Chapter 8**.

2 WORLD
Energy Outlook

The global outlook for energy depends on a number of factors, including population growth, economic development, environmental limits, and all of the things that affect them.[11] There is a natural and obvious distinction between developing countries and industrialized countries that must be recognized when considering how the future may unfold. Behaviour in these disparate regions will differ strongly, as will the resulting implications for energy use. The rest of this chapter has been organized in two sections. Section 2.1 presents an account of the historical and the expected changes in world population and the Human Development Index (HDI) to set the scene for energy scenario analysis. Section 2.2 deals with the world energy plausible futures. It describes and comments on the two different sets of scenarios developed by the International Energy Agency (IEA).

2.1 World Population and Human Development

World population is projected to increase by some 2.5 billion people, from its current level of 6.6 billion, by the middle of the 21st century. Since almost all of the increase will be concentrated in developing countries, thirsty for energy, energy demand will grow even faster. Although modern economies are critically dependent on a reliable and affordable supply of energy, roughly 2 billion people currently do not have access to electricity in daily living. The developing world is not likely to accept limitations on either the form or the quantity of energy it uses prior to reaching some acceptable standard of living commensurate with other countries. That means the international demand for reliable energy supplies will increase over the foreseeable future.

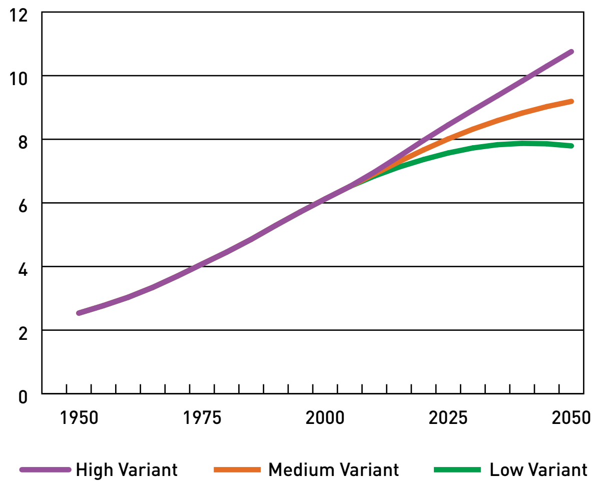
In Figure 2.1 we show historical data for population growth and forecasts based on estimates from the United Nations. In 2000 the world's population was estimated at a little over 6 billion people. Under all forecasts, population is growing. The range of forecasts is substantial, from approximately 7.8 to 10.8 billion people by 2050.

The major sources of uncertainty in population forecasts are assumptions regarding fertility rates, which are defined as the average number of children born per woman. A total fertility rate of 2.1 is needed to replace current populations. Current estimates indicate that in many developed countries the total fertility rate is now significantly below this level.

[11] This chapter draws heavily on the discussion of scenarios in the International Energy Agency publications *Energy to 2050: Scenarios for a Sustainable Future,* Paris, France, 2003; and *Energy Technology Perspectives 2006: Scenarios and Strategies to 2050,* Paris, France, 2006.

Figure 2.1

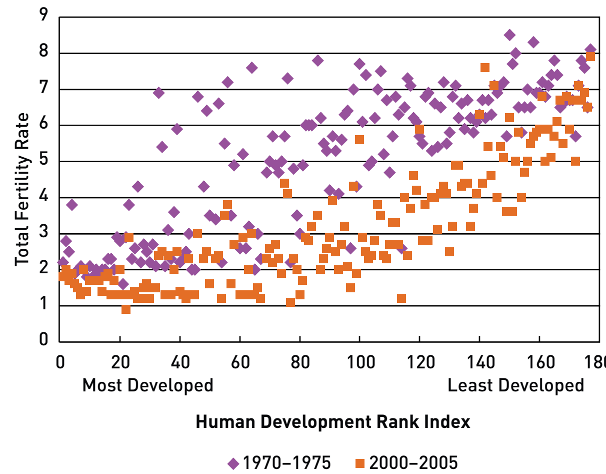
World Population, 1950–2050 (billions)



SOURCE: United Nations Population Division, World Population Prospects: The 2006 Revision*, tables at http://esa.un.org/unpp/p2k0data.asp*

Figure 2.2

Total Fertility Rate and Human Development Index



SOURCE: United Nations Development Programme, Human Development Report 2006, Beyond Scarcity: Power, Poverty and the Global Water Crisis*, accessed at http://hdr.undp.org/hdr2006/pdfs/report/HDR_2006_Tables.pdf*

Estimates also indicate an unprecedented decline in fertility even in some developing nations. This largely unexpected decrease has led to the lowering of population forecasts.

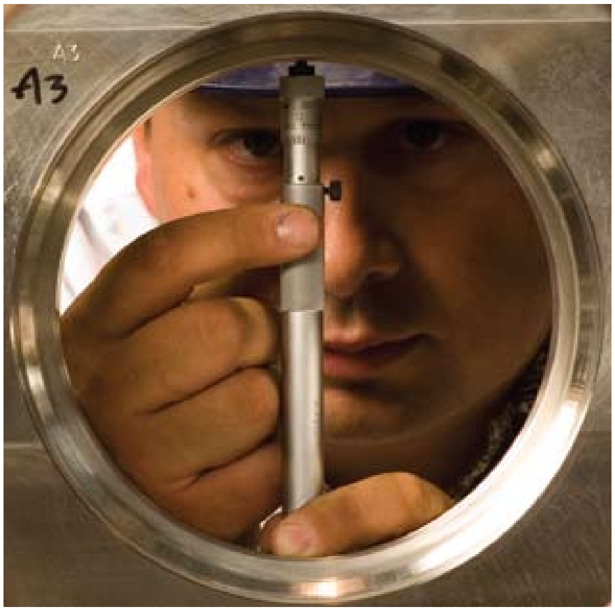
In Figure 2.2 we show the relationship between an index of human development and estimated total fertility rates in the periods 1970–1975 and 2000–2005. The United Nations Development Programme defines this index as a combined energy average achievement by country in longevity, knowledge, and standard of living.[12] This graph shows a clear decline in estimated total fertility rates from the period 1970–1975 to 2000–2005, particularly among the countries near the middle in terms of HDI rank.

Figure 2.2 also shows that even though fertility rates have declined significantly, large differences still persist between the most developed and least developed nations. The total fertility rate for Canada is estimated to be 1.5, indicating that without continued immigration Canada's population would likely begin to decline. For the US estimated total fertility is 2.0, indicating that without immigration the total population would remain relatively stable. Overall, the UN expects that by 2050 population in Canada will have risen from approximately 32.6 million to 42.8 million. The US population is expected to rise from 301 million people to 402 million people by 2050.

It is in the least developed countries that the total fertility rate is expected to be highest and where most of the growth in population is expected to occur. High population growth rates are expected in most African nations, despite the ravages of the HIV/AIDS crisis. For some nations, the decline in the total fertility rate over the last 30 years has been dramatic. For example, China's fertility rate declined from an estimated 4.9 in 1970–1975 to 1.7 in 2000–2005. The UN's "medium" population forecast indicates only modest population growth (from 1.35 to 1.41 billion people between 2000 and 2050).[13]

[12] See http://hdr.undp.org/hdr2006/pdfs/report/HDR06-complete.pdf, p. 263 for further details.

[13] In comparison, the "high" scenario estimates population to grow to approximately 1.65 billion people by 2050.



2.2 Future of Energy and Energy Systems

With the basic population driver as background, we turn now to a discussion of how to look at the complex relationships that will determine the future of energy and energy systems. Our discussion of future energy needs and supplies must begin by acknowledging that we are dealing with a vast interconnected system that embodies the potential to evolve in alternative and very different ways. This is the subject of a great deal of academic literature and review by government and international agencies. We can only touch the surface in this overview, and the interested reader should consult the bibliography for a sampling of available commentary.

For a more comprehensive coverage of differing views on the future of energy, we are presenting overviews to two different but somehow complementary scenario-based reports by the International Energy Agency (IEA). The first report published in 2003, sets different assumptions on the economic growth, population growth, energy demand, etc. for each of the scenarios which extend to 2050. The second report published in 2006, however, focuses on the various plausible levels of advancement in technology and evaluates possible levels of emissions control under those scenarios. The underlying assumptions on economic growth and other parameters remain the same for all possible scenarios.

2.2.1 The IEA 2003 Scenarios for a Sustainable Future

We have chosen to use an abbreviated approach to scenario description to convey our views about possible future developments in energy. We have adopted a limited set of scenarios, developed by the International Energy Agency (IEA),[14] both to simplify the discussion and to capture some of the major areas of diversity in likely futures. Scenarios are not forecasts, prophecies, predictions, or even guesses about the future. They are better described as sketches or illustrations, portrayals or representations of possible alternative future states. The scenarios set out in this section are intended to be descriptive as opposed to prescriptive. They seek to explain possibilities rather than provide guidance on how to achieve a desirable outcome through policy or other means. Moreover, they are based in narrative, not numbers. We do not seek testable models or even numerical consistency among the defining variables discussed here; we seek clarity in explaining the issues that emerge from the complex interaction of energy, environment, and economy.

2.2.1.1 Defining the Possible Futures

In the introductory review, we identified population growth and energy intensity as the broad drivers of demand for energy. At the global level, these factors have differing levels of importance, depending on the level of development of each country.

In the developing countries, approximately one-third of the world's population, or some 2 billion people, do not have access to forms of energy that are taken for granted in more developed regions. Rather, they rely on traditional forms of energy such as wood and animal waste suitable for burning for heat and cooking. The people in these countries allocate a significant portion of their time to gathering energy for survival and therefore realize slower economic growth.

As well, the populations of these countries continue to grow at relatively high rates compared to the developed world for reasons having to do with security and survival. Within these countries, as the economies become more complex and urban populations grow,

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[14] International Energy Agency, *Energy to 2050: Scenarios for a Sustainable Future*, Paris, France, 2003.

there is increased upward pressure on the demand for energy. This leads to constantly growing demands for hydrocarbon fuels, since these are the most easily used to meet the needs of such populations. As countries develop economically, they achieve greater access to energy sources such as electricity, and the growth in population slows, slowing the growth in energy demand as well.

In more developed countries, the production, conversion, and delivery of energy provide impetus to economic growth. Such countries exhibit lower growth in population, and appear to have achieved some balance between birth and mortality. These countries have some scope to reduce their use of hydrocarbon-based fuels since they can afford to subsidize renewable forms of energy as well as to finance improvements in technology that, over time, will increase the efficiency with which energy is used.

Thus, global problems — and the incentives to resolve them — vary across countries and, without some coordinated action, the likely result is growing disparity.

On the supply side, there appear to be adequate global supplies of hydrocarbon-based energy sources (oil, gas, and coal) for between 50 and 100 years at least. While the prices associated with this energy can be a burden to developing countries, industrialized countries can both afford and finance them.

2.2.1.2 The View from 50,000 Feet

From above the clouds, the future of the energy system is available in outline only. Here we can usefully consider one such outline based on the standard "business as usual" case. In other words, we rely on past trends to define or project a possible future. This allows us to draw implications based loosely on later chapters that describe past trends, but it also requires us to make assumptions that may be questionable. The assumption that there is little change in future approaches to managing the energy/environment interaction can be challenged on a number of grounds. For this section, our purpose is to set out a snapshot of a possible future based on continuing past practices.

Despite the great promise of renewable energy, hydrocarbon fuels continue to dominate.

2.2.1.3 A Trend-Based Future

Based on the past we know, this plausible future will have the following main characteristics:

- Population continues to grow. By 2050, the 6 billion people reported at the turn of the century will be 8 to 11 billion. Most of the growth in population occurs in the developing world, and urbanization continues.
- Since population growth is concentrated in developing countries, where economic growth requires large increases in the use of energy, overall demand for energy grows faster than world population. So energy use nearly doubles, from some 400 quads in 2000 to roughly 800 quads by 2050.
- Despite the great promise of renewable energy, hydrocarbon fuels continue to dominate. Renewable energy grows at high rates, but starting from a very small base, with higher costs and less capacity to meet the needs of the systems, it cannot make a significant contribution.
- The efficiency of energy use continues to increase in the developed world. To achieve their goals, people in the developed world adopt cheap and available hydrocarbon fuels, while accepting the inevitable emissions.
- For 30 to 50 years, this strategy can be maintained from the existing resource base, although environmental considerations may become more and more pressing.


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This future may be altered by relatively faster advances in technology or by aggressive policy initiatives to foster change. However, its progress may be moderated if existing capital stock turns over slowly and new technology takes time to permeate the system.

Given this likely future extrapolated from past trends, and recognizing that significant change will require time and effort, and is unlikely to occur quickly, we turn to the recent IEA study to assess alternative future prospects.

The essence of such work is the uncertainty associated with the future. Given our inability to see the future reliably, we seek ways to define appropriately flexible strategies. Exploratory scenarios assist in identifying the likely drivers that shape the future as well as how they interact. Normative scenarios define the desired future and look for the policy guidelines that will take us toward it. We focus on the former here, as our purpose is to clarify alternatives, not prescribe solutions.

There has been a large effort over more than 30 years to define and refine the modelling and scenario approach to planning. What follows is a summary of that work, largely based on the IEA publication *Energy to 2050*, in which the IEA presents three explorative scenarios.[15] The result is attractive for both its clarity and its simplicity.

2.2.1.4 The IEA Scenarios

Seven main drivers are identified that could strongly affect the system and that are also directionally uncertain. These are ranked from most to least important, as follows:

- Rate of change of technology (demand and supply)
- Attitudes toward the global environment
- Economic growth
- Population growth

[15] The IEA also focused much effort on normative scenarios intended to provide guidance to identify the measures that would be required to achieve a desirable future. We avoid that discussion here as it goes beyond the scope of this report.

- Globalization and degree of market openness
- Structure of power and governance
- Global security issues

2.2.1.5 How the Scenarios Differ

The three scenarios are assigned titles intended to convey their main features:

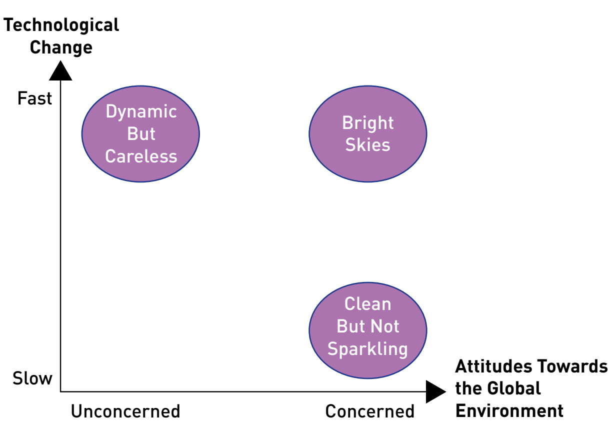
- Clean But Not Sparkling (slow technological change, high concern for environment)
- Dynamic But Careless (fast technological change, low concern for environment)
- Bright Skies (fast technological change, high concern for environment)

The scenarios are defined with respect to the two main drivers assumed to dominate how the future evolves.

- While technological progress continues in all scenarios, progress in some is specifically encouraged and more rapid.
- Likewise, while local environmental concerns are assumed in all scenarios, some have a higher policy emphasis on global environmental concerns.

Figure 2.3 illustrates the positioning of the three scenarios, with technological change on the vertical axis and attitudes towards the global environment on the horizontal axis. The fourth, unnamed scenario, near the origin, would approximate our "Business as Usual" case, which historically has been relatively unconcerned with the global environment and exhibited little conscious interest in accelerating technological change.

Figure 2.3
Three Exploratory Scenarios



SOURCE: International Energy Agency, Energy to 2050: Scenarios for a Sustainable Future, *Paris, France, 2003.*

2.2.1.6 Characteristics Shared by the Scenarios

The scenarios share some characteristics that are familiar from our earlier discussion and others that emerged from the preliminary analysis.

Population
Growth continues, though more slowly than in the past. This population growth is focused on the developing world, with urbanization resulting in 80 percent of the population in cities by 2050 and mega cities emerging, especially in the developing world.

Income Level and Growth
Economic growth continues to improve, with developing countries growing faster, the service sector increasing in importance, and focus on knowledge becoming a source of relative advantage for some countries.

Energy Supply
The hydrocarbon resource base is assumed to be adequate through 2050, although regional disparities and geopolitics may differentiate the scenarios.

Energy Demand
Energy demand continues to increase in all scenarios, but more rapidly in developing countries than in industrialized nations. However, technological change in all scenarios continues to facilitate lower energy intensity and may allow greater efficiency in developing countries than was historically observed in industrialized countries at similar stages of development. Electrification continues in the developed world and increases in the developing world. This will require new infrastructure in many regions and pose a financing challenge in some countries.

Concern for the Environment
Economic development will cause some greater environmental problems and, through its generation of affluence, lead to broadly increasing concern for the environment. Some level of environmental awareness is part of every scenario.

Increasing Liberalization and Interdependence
Increasing openness of markets and growing interdependence may speed the transfer of knowledge and help narrow the income gap quicker than otherwise. Scenarios emphasizing environmental concern may involve more pronounced government action on climate change.

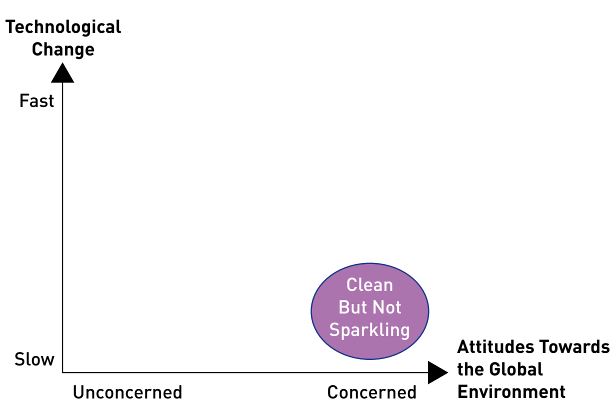
2.2.1.7 A Summary of the Scenarios

The following discussion illustrates the differences among the scenarios and comments on the inherent uncertainties. One contribution of scenario assessment is to reveal the uncertain aspects related to the evolution of complex systems such as the world economy. Each scenario runs from 2003 to 2050, considered in three intervals, but the intervals differ for each case.

Scenario 1: Clean But Not Sparkling
This scenario (see Figure 2.4) embodies strong concern for the global environment, but for various reasons technology advances slowly, which precludes some otherwise available environmental gains. One explanation might be that environmental policy is focused on behavioural changes that are relatively costly to industry and individuals and that might deflect investment away from technology improvement.

- Environmental policy is stringent in the first 25 years and individuals in developed countries buy in to the "green" approach of driving less while walking, using mass transit, and cycling more.

Figure 2.4
Scenario 1



SOURCE: International Energy Agency, Energy to 2050: Scenarios for a Sustainable Future*, Paris, France, 2003.*

The Kyoto Protocol is adopted and renewed in the second commitment period. Gas increasingly becomes the fuel of choice, with attendant benefits relative to displaced coal and oil.

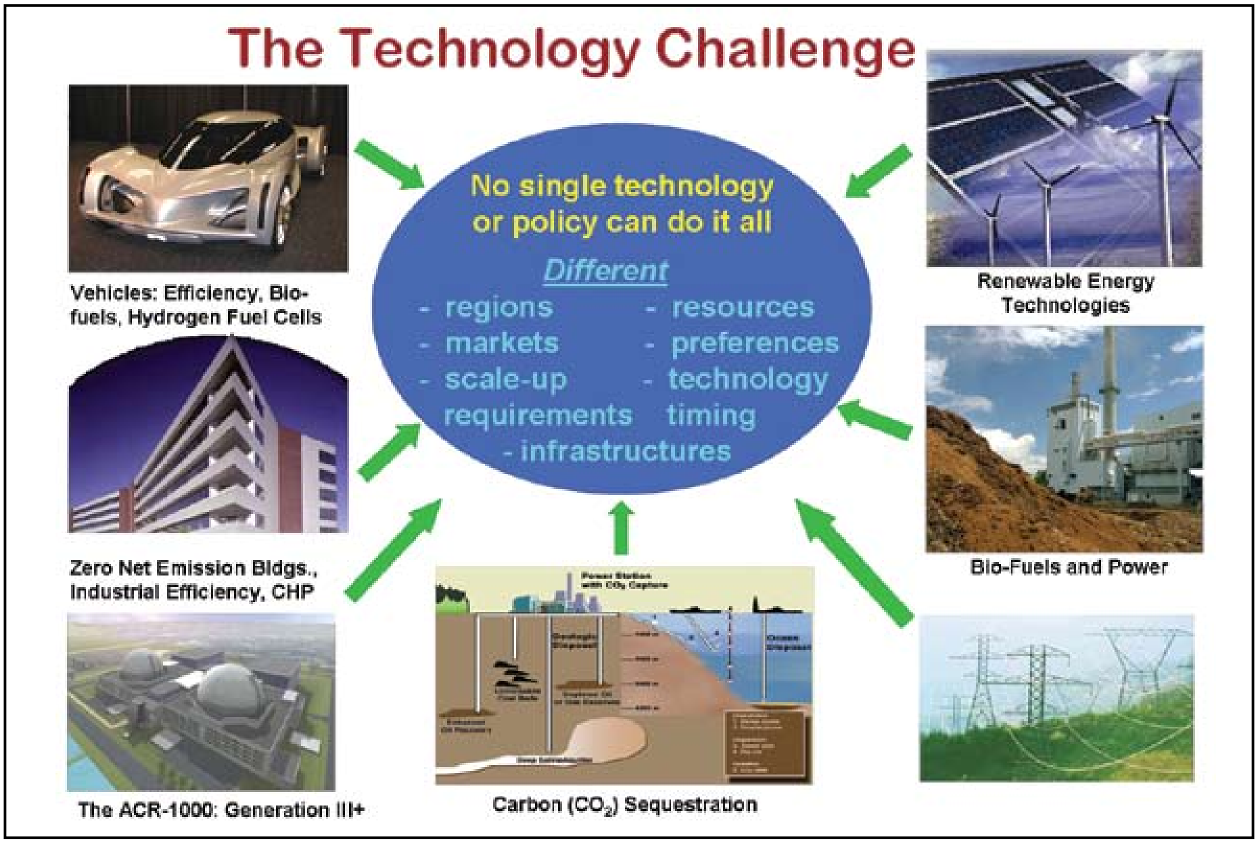
- Over the next 25 years, emissions are stable but not declining, and the costs of climate change start to be felt, as do increasing energy costs. Developing countries continue to grow, leading to increased incomes but also increased emissions. Now these countries buy in to controlling emissions, but technological change has lagged and the capital stock is relatively new. The advances in technology that have occurred are not able to displace existing capital until near the end of the period.
- While the emission curve eventually bends down, by 2050 continuing improvement is difficult and results in lower growth. Now changes in behaviour involve sacrifices and are harder to accept.

"The outlook for 2050 shows a world that is labouring to further reduce GHG emissions, aiming at stabilising their concentrations but doing so at the cost of lower economic growth and of relatively important behavioural changes — some easy to accept, others perhaps less easy to live with."[16]

Scenario 2: Dynamic But Careless
In this scenario (see Figure 2.5), technology improves rapidly and economies grow, buoying incomes and fostering the belief that technology will resolve environmental issues. Kyoto is adopted, but lapses after Phase 1, with few countries achieving the targets.

- Initial gains in technology relate to fossil fuels, keeping prices low, bolstering demand, and leading to increased GHG emissions.
- As demand grows, prices firm, causing more exploration for fossil fuels and greater emphasis on their efficient use through technological advances. Both developed and developing countries focus on finding new supplies of fossil fuels and controlling low-cost sources of supply, leading to a resurgence of concern about security of supply.

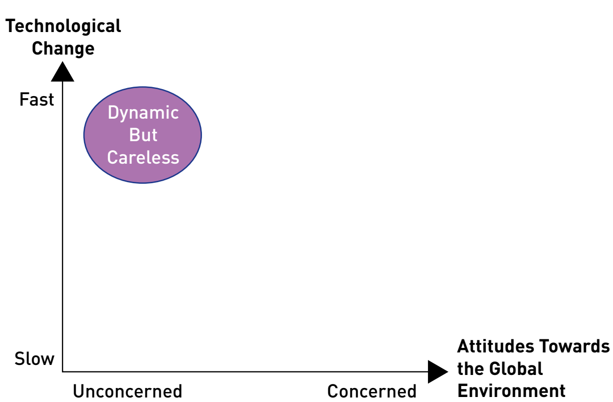
[16] International Energy Agency, *Energy Technology Perspectives 2006: Scenarios and Strategies to 2050,* Paris, France, 2006, p. 78.



- Continuing reliance on fossil fuels leads to geopolitical strain, as producing areas seek higher prices and consumers seek security and economy. Technology continues to focus on the supply side, such as coal gasification, enhanced recovery, and end-use applications.

- Over time, GHG emissions increase, leading to new emphasis on the global environment. Nuclear power gains acceptance, and hydrogen and fuel cell research increases. Sequestration of carbon dioxide (CO_2) is adopted to a greater extent as the adverse potential from continuing emissions is broadly accepted.

Figure 2.5
Scenario 2



SOURCE: International Energy Agency, Energy to 2050: Scenarios for a Sustainable Future*, Paris, France, 2003.*

"Development on a large scale of the energy options illustrated above would lead to an improvement of local air quality in both developed and developing countries and even to a significant slowdown of GHG emissions growth in developed countries, gradually spreading to developing ones towards 2050. Over the period, this scenario produces much higher emission concentrations than the first one — but may create the technological conditions for more rapid reductions beyond 2050. Adoption of these new technologies would take place as they become increasingly competitive, and in light of their clear superiority in terms of cleanliness. In the case of hydrogen this advantage would be coupled with comparable ease of use with respect to conventional energy carriers."[17]

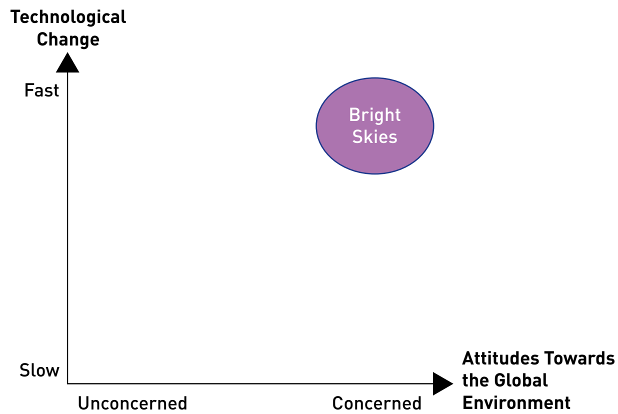
[17] *Ibid.*, p. 90

Scenario 3: Bright Skies

In this scenario (see Figure 2.6) rapid technological change occurs, and both individuals and governments exhibit a strong favourable attitude toward the global environment. Economic growth is somewhat less than in Scenario 2, but greater than in Scenario 1. The developed countries agree to a coordinated approach to the environment that involves a greater emphasis on technology, eventually attracting the developing countries, which now have sufficient growth to allow them to focus on the global condition.

- The environmental imperative is recognized at both individual and government levels following some extreme climate events and a continuing international debate. The insurance premium approach prevails, and a two-pronged approach to the problem emerges: reducing the environmental footprint of human activity, and focusing on technological improvements in both demand and supply areas to enable greater ultimate reductions in emissions.
- The pressure on fossil fuels is reduced relative to the other two cases, so that security concerns and geopolitical stresses are relatively less.
- The developed countries bear most of the burden early on, but their acceptance of this responsibility, coupled with the higher growth the approach allows in the developing world, is helpful in convincing the latter to eventually make similar commitments.

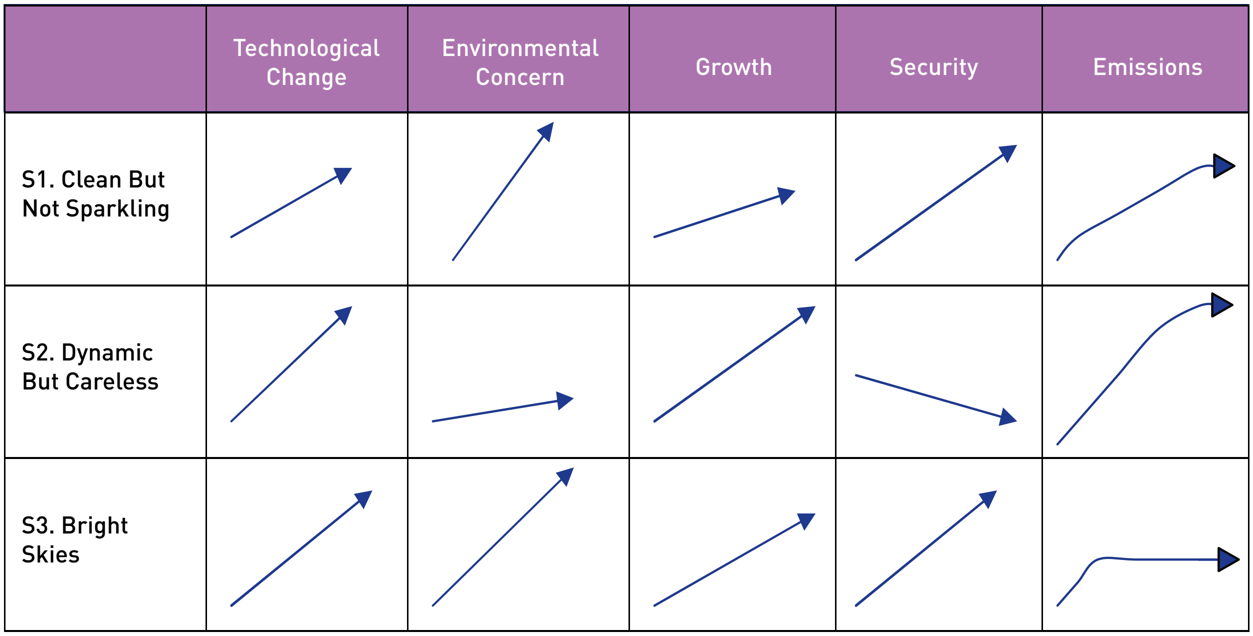
Figure 2.6
Scenario 3



SOURCE: International Energy Agency, Energy to 2050: Scenarios for a Sustainable Future, *Paris, France, 2003.*

- Carbon sequestration is encouraged, as is an emphasis on switching to low-emission fuels such as natural gas.
- Nuclear power gradually gains acceptance as technologies improve and the general understanding about risks, costs, and benefits of the nuclear option increases.
- At an individual level, initiatives such as car pooling, investment in home efficiency and more efficient and friendly mass transit have a significant effect on reducing energy use and therefore emissions.

Figure 2.7
Three Exploratory Scenarios — Qualitative Directions of Change



- In the longer term, technologies for power production become critical, not only in traditional uses, but also increasingly in transportation. This leads to increased use of renewable forms of energy — wind, solar, tidal, geothermal, and others.
- The increasing acceptance and use of nuclear power production does not preclude the search for nuclear fusion, although success there is not likely until closer to the end of the century.
- Hydrogen becomes economically available as a result of nuclear production, and fuel cell technology continues to improve, in both mobile and stationary applications.

"As a result of large international research efforts, it is likely that significant breakthroughs in one or more of these technologies would be made before the end of the scenario horizon considered, thus providing a long-term answer to the problem of climate change mitigation without significantly restricting economic growth and the satisfaction of future energy demand for energy services."[18]

[18] *Ibid.*, p. 100

2.2.1.8 Discussion and Commentary on the Implications of the Three Scenarios

The three scenarios cover a range of possible futures, each of which is plausible, with differing implications. To assess that range, the IEA set out a table of directional changes in important elements. That table is reproduced above. It attempts to capture visually some of the differences in the three scenarios as a way of summarizing the analysis. For example, Scenarios 2 and 3 emphasize technological change more than does Scenario 1. Resulting emission profiles show Scenario 1 with a larger impact in early years but relatively less successful reductions in later years as the technology adopted in 2 and 3 takes greater effect. Thus, Scenario 1 delays the acceptance of nuclear power as a way to contribute to the solution, in part because the focus on emissions reduction diverts capital from technological pursuits. In Scenario 2, nuclear power is initially expensive; but because of a greater emphasis on technology, nuclear power becomes both more widely accepted and more economical, thus enabling a greater contribution to meeting energy needs while also enabling more significantly reduced emissions in later years. Scenario 3 not only adopts nuclear power at an early stage; it also focuses on other technology with long-term potential, yielding an even greater payoff in terms of later-year emissions reduction.

Similarly, Scenario 2, with its reduced emphasis on near-term emissions, results in accelerated development of fossil fuel resources. The emphasis on oil and gas leads to earlier dependence on supplies exported to/imported from various regions, with a consequent reduction in the level of security related to those supplies, so the security arrow goes down in that scenario.

The essence of this approach to looking at the potential outcomes is to recognize the critical interaction of technology and environment and acknowledge the importance of both to achieving secure, sustainable economic growth. That acknowledgment in itself may contribute to a more balanced approach to meeting the energy needs of the future without endangering our capacity for sustainability.

2.2.2 The IEA 2006 Technology Scenarios

The International Energy Agency, in its report[19] *Energy Technology Perspectives 2006: Scenarios and Strategies to 2050* extended the number of scenarios and focused on the key technologies that it believes will usher in a more sustainable energy future. Figure 2.8 groups those technologies into five categories. To this end, development and improvement of appropriate technologies appear to be the way forward in enabling energy producers and energy consumers to reduce their emissions.

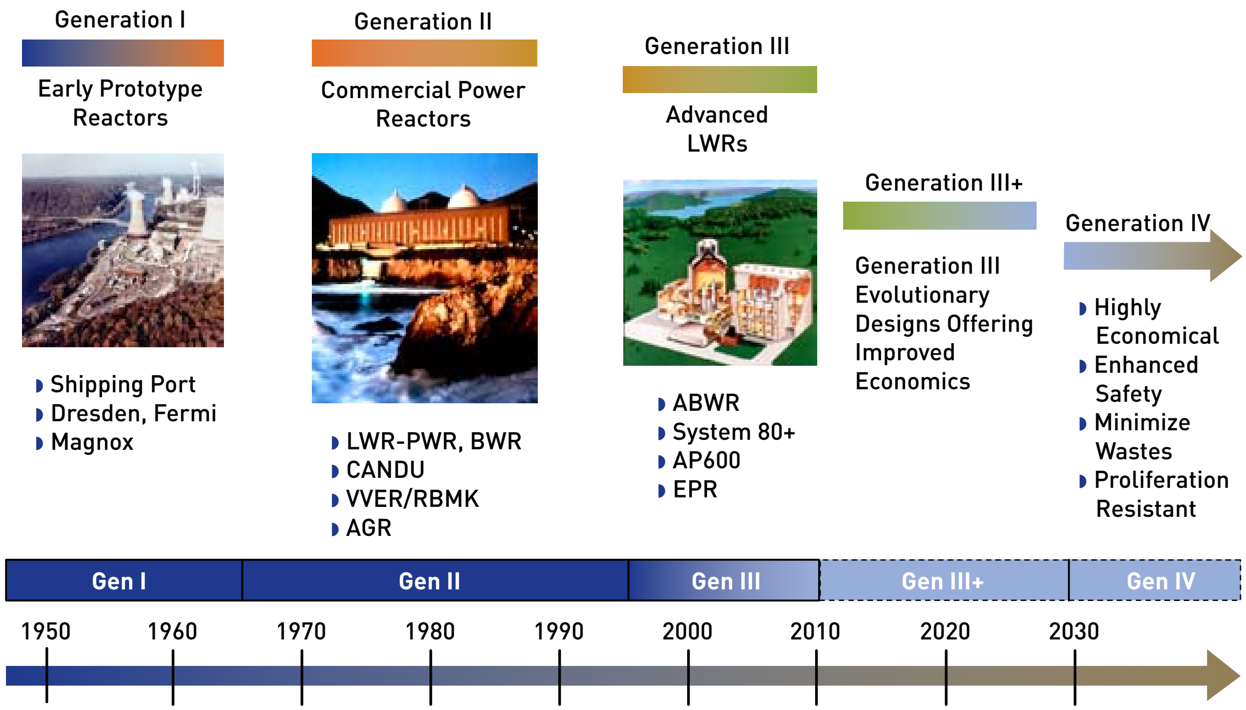
The IEA examined the potential impact of energy technologies in developing a future energy supply mix and assessed their effect on reducing energy emissions. The scenarios focus on key technologies which exist or are under development, and have the potential to

Figure 2.8
Major Current and Future Technologies

Technology Strategies for a More Sustainable Energy Future				
Renewables	**Industrial**	**Nuclear**	**Transportation**	**Buildings**
Bioenergy	CO_2 Capture and Storage	Advanced Boiling Water	Biofuels	Appliances
Geothermal	Combined Heat and Power Generation	Advanced Gas Cooled	Electrification	Cooking
Hydro (Light and Small)	Energy Efficiency	Boiling Water	Fuel Cell	Lighting
Ocean	Fuel Substitution	Fast Breeder	Hydrogen	Space Heating and Cooling
Onshore and Offshore Wind	Waste Recycling	Gas Cooled	Internal Combustion Engine	Water Heating
Solar Photovoltaic		Light Water Cooled	Light Materials	Windows and Insulation
Solar Power		Pressurized Heavy Water	Synthetic Fuels	
		Pressurized Water		

19 International Energy Agency, *Energy Technology Perspectives 2006: Scenarios and Strategies to 2050,* Paris, France, 2006.

Figure 2.9
The Evolution of Nuclear Power



SOURCE: Canadian Nuclear Association, Annual Seminar, IEA (Robert Dixon).

reduce future global energy-related CO_2 emissions relative to what we are experiencing at present.

The report finds that in the baseline scenario, global growth of CO_2 emissions is fast, significant and unsustainable. Furthermore, energy security will remain as an unresolved issue.

The IEA shows that the achievement of energy security and sustainability relies on the development and implementation of current and new technologies. The IEA developed five Accelerated Technology (ACT) scenarios — Map, low renewables, low nuclear, no Carbon Capture and Storage (CCS), and low efficiency — in addition to the TECH Plus scenario. The ACT Map considers five technologies, namely: renewables, nuclear, CCS, biofuels, and end-use efficiency. The TECH Plus scenario considers the above five technologies plus hydrogen fuel cells (Figure 2.10).

It should be noted that the objective of the IEA's scenario analysis was not to develop a forecast but to illustrate possible outcomes based on a thorough analysis of the characteristics and potential of current technologies.

In the IEA scenario analysis, the divergence in outcomes among the scenarios reflects different assumed rates of progress in overcoming technological barriers and achieving cost reductions. For example, the ACT Map scenario is relatively optimistic across all technologies while each other ACT scenario (renewables, nuclear, no CCS, efficiency) is pessimistic about a specified technology; the TECH Plus scenario is more optimistic than the ACT Map scenario about progress in overcoming technological barriers.

The IEA considers the historical development of the nuclear power industry in terms of four generations[20] (Figure 2.9). Historical Generation I (1950s–1960s) and Generation II (1970s–1990s) represent the prototype and commercial reactors respectively. Generation III (1995–2010) represents advances in technology along with more safety and economics.

[20] www.ne.doe.gov/genIV/neGenIV1.html and www.cna.ca/seminar2007/docs/presentation_dixon.pdf

Figure 2.10
Major Scenario's Assumptions

Scenario	Renewables	Nuclear	Carbon Capture and Storage (CCS)	H_2 Fuel cells	Advanced Biofuels	End-use Efficiency
ACT Map		Relatively optimistic across all technology areas				2.0% p.a. global improvement
ACT Low Renewables	Slower cost reductions					
ACT Low Nuclear		Lower public acceptance				
ACT No CCS			No CCS			
ACT Low Efficiency						1.7% p.a. global improvement
TECH Plus	Stronger cost reductions	Stronger cost reductions and technology improvements		Breakthrough for FC	Stronger cost reductions and improved feedstock availability	

SOURCE: International Energy Agency.

Future Generation III+ and Generation IV represent capital cost and construction time reductions and longer operating life. Future generations are incorporated in the ACT and TECH Plus scenarios.

The other major assumptions and distinguishing features of each scenario (Figure 2.10) as described by the IEA report[21] are presented above.

2.2.2.1 ACT Map

The key features of the ACT Map scenario that distinguish this scenario from the others are:

- Continuing cost reductions for renewable energy technologies.
- Resolving waste management issues and increasing public acceptance of nuclear power generation expansion.
- Overcoming barriers to the capture and storage of CO_2.
- Achieving steady gains in energy efficiency and improvements in energy use in the transportation, construction, and industrial sectors, due to the adoption and implementation of more energy-efficient technologies.
- Substituting biofuels for petroleum products to a greater extent.

[21] International Energy Agency, *Energy Technology Perspectives 2006: Scenarios and Strategies to 2050,* Paris, France, 2006, p. 40.

2.2.2.2 ACT Low Renewables

This scenario explores the impact of slower cost reductions for wind and solar energy technologies compared to the ACT Map.

2.2.2.3 ACT Low Nuclear

This scenario postulates limited growth for nuclear energy if related waste issues are not resolved satisfactorily.

2.2.2.4 ACT No CCS

This scenario explores what would happen if the technological issues facing CCS are not solved and CCS technologies do not become commercially available.

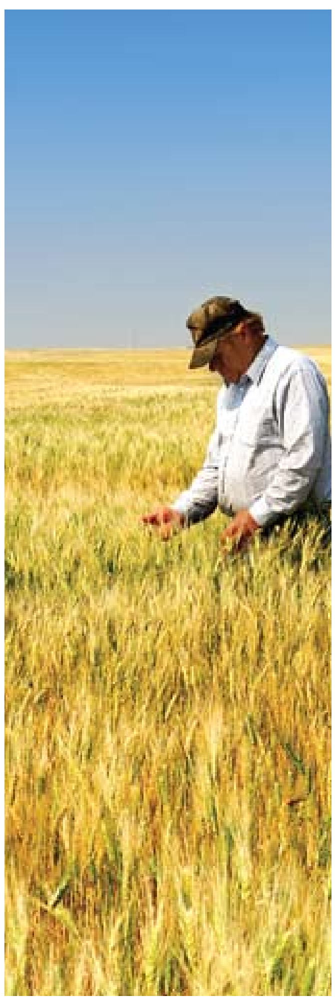
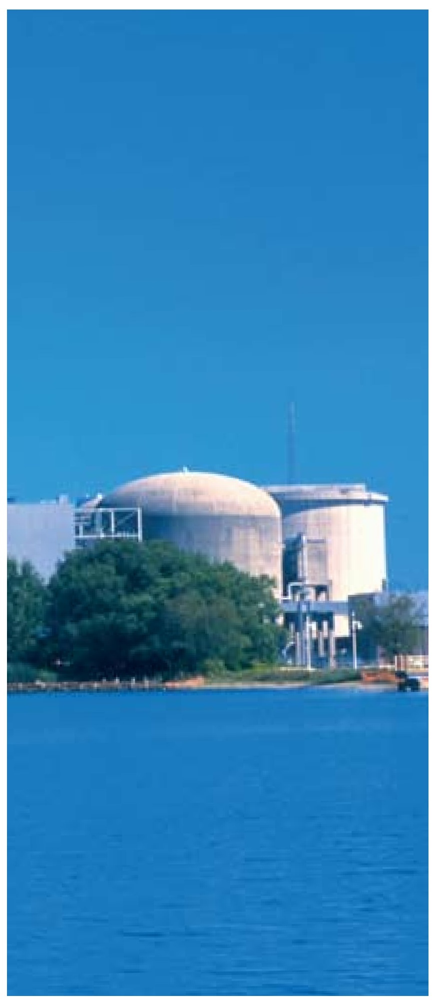
2.2.2.5 ACT Low Efficiency

This scenario assumes that global energy efficiency improvements would be 0.3 percentage points per year lower than in the ACT Map scenario.

2.2.2.6 TECH Plus

The TECH Plus scenario makes more optimistic assumptions about progress in overcoming technological barriers than the ACT Map scenario does: greater cost reductions for fuel cells, and more rapid progress in renewable electricity generation technologies, biofuels and nuclear technologies. Under this scenario, the shares of both renewable and nuclear energy in electricity generation will increase, and hydrogen fuel-cell vehicles (FCVs) will gain significant market share.

The macroeconomic and demographic assumptions are the same for all scenarios. World economic growth is taken to be 2.9 percent per year between 2003 and 2050, with per capita incomes rising 2 percent per year on average. Energy prices in each scenario reflect scenario-specific changes to energy demand and supply. The IEA outlook to 2050 for each scenario is presented in Section 5.7.


3 HISTORICAL ENERGY
Consumption

Over the last 150 years, the consumption of energy in the world has multiplied more than 30-fold. From 1860 until 1945, the average annual rate of increase in the use of energy was 2.2 percent. During this period, the world population grew from about 1 billion to 2.5 billion and average GDP increased by more than 1.5 percent annually. For the most part, this increase in energy consumption was for industrial uses. Coal was dominant.

From the end of World War II until the energy crisis of the early 1970s, the average rate of increase in energy consumption was 4.9 percent per year. The world population increased to 4 billion people. On average, GDP grew by some 5 percent per year. Oil became a dominant form of energy.

From the energy crisis until the early 2000s, the rate of increase in energy consumption slowed to an average of 1.7 percent per year. The world population increased by an additional 2 billion, but GDP growth declined to some 3 percent on average. With massive urbanization, energy-related environmental issues became a major concern. In this decade, global energy consumption growth has exceeded 2 percent.

Table 3.1
Growth Rates in World Energy Use, 1860–2006

1860–1945	2.2%
1945–1973	4.9%
1973–2000	1.7%
2000–2006	2.6%

SOURCES: Peter R. Odell, Why Carbon Fuels Will Dominate the 21st Century's Global Energy Economy, *Multi-Science Publishing Co. (1860–2000); British Petroleum Company,* BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007 (2000–2006).*

3.1 Energy Demand Drivers

Three forces, discussed above, drove this historical increase in the need for energy:

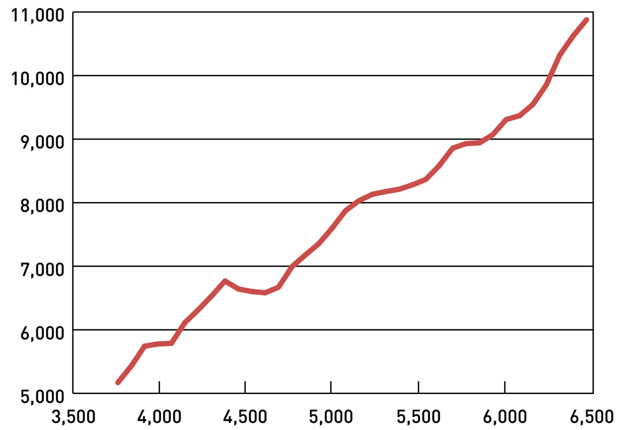
- Population growth
- Economic growth
- Energy intensity

3.1.1 Population Growth

Historically, as world population has increased, so inevitably has energy demand. This is evident from Figure 3.1.

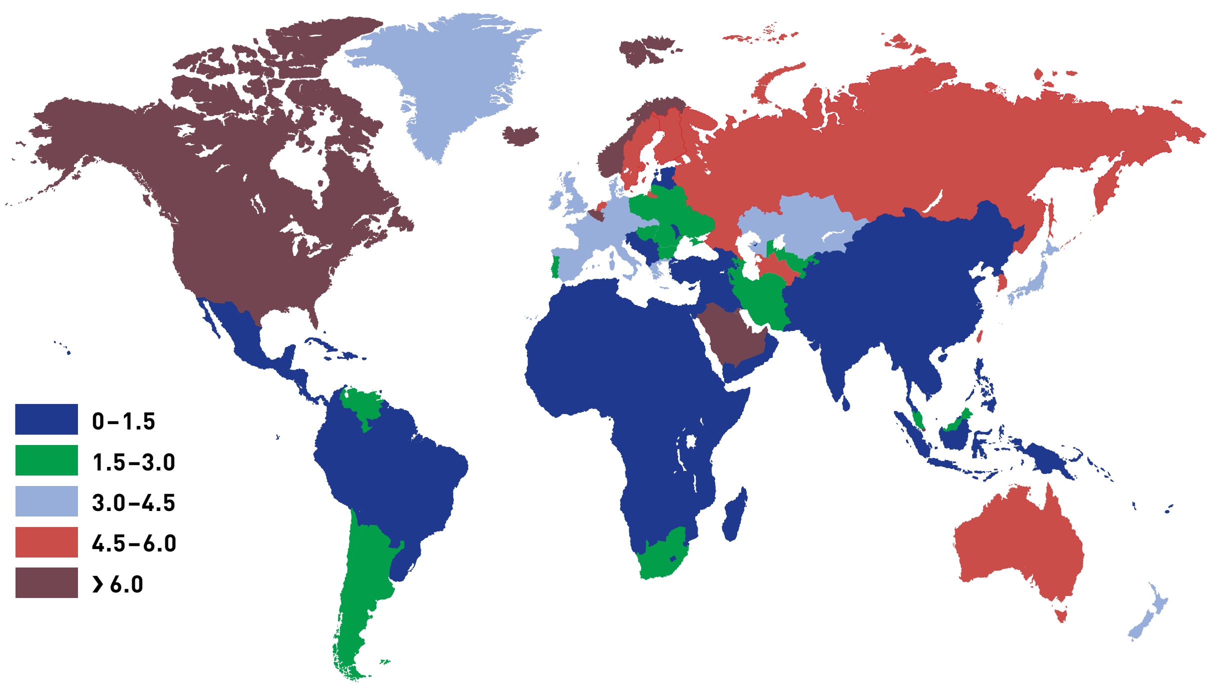
While population growth generally leads to higher energy demand, the amount of energy consumed per capita varies greatly across the world. In Figure 3.2 we show the energy consumed per capita (measured in tonnes of oil equivalent).

Figure 3.1
Relationship Between World Energy Consumption and World Population, 1971–2006



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

Figure 3.2
Primary Energy Consumption Per Capita (tonnes of oil equivalent)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

The reasons for the differences in per capita energy consumption are as important in determining energy demand as are increases in population. As an illustration, if per capita energy consumption worldwide were as high as it is in the United States, total world energy demand would be four to five times as high as its current level.[22]

3.1.2 Energy and Economic Activity

There is a direct link between levels of economic activity and energy consumption. In Figure 3.3 we show annual percentage changes in energy use and in total economic activity (measured by GDP) for the United States and Canada over the period 1980 to 2006. As the economy has grown (measured by increases in GDP), so has the demand for energy.

In Figure 3.4 we plot economic activity and energy use. It is easy to conclude that total energy demand (taken as equal to total primary energy supply on a global basis) is highly correlated with total economic activity.

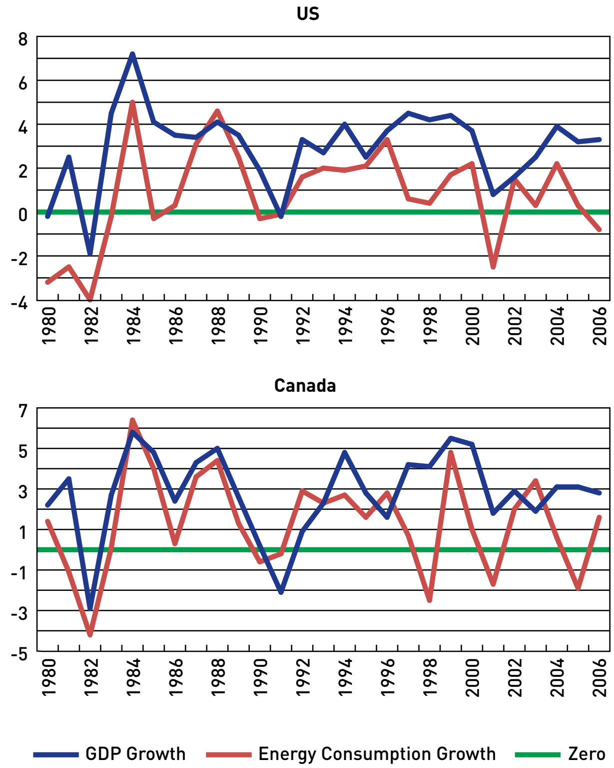
It is more revealing to consider the link between GDP and energy use on a per capita basis, as shown in Figure 3.5. On a per capita basis, there is still a clear link between economic activity and energy use, but for a given income the range of energy consumption is quite large. Some countries, like Norway and Japan, enjoy relatively high standards of living but have much lower energy intensity.

One reason for the variation in per capita energy consumption is that some countries have higher per capita incomes, and the activities used to generate these incomes typically consume more energy.

It is possible to distinguish a number of factors associated with higher levels of economic activity (economic growth) and energy use. Among the contributing factors are the vast geographic area over which life takes place in Canada and the US and the climate in the northern parts of this region.

Figure 3.3

Energy Use and Total Economic Activity in the US and Canada, 1980–2005* (percent)

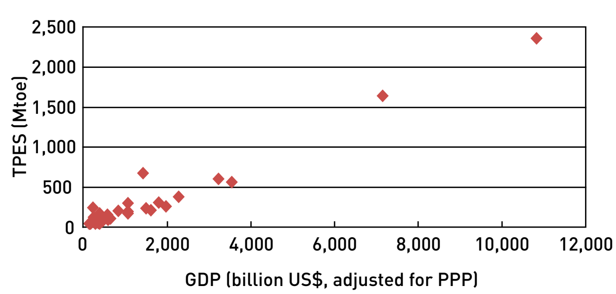


** Gross domestic product is adjusted for purchasing power parity (PPP). This adjustment is intended to account for differences in exchange rates that may not reflect the true value of the currency.*

SOURCES: Energy Information Administration, accessed at www.eia.doe.gov/emeu/international/populationandgdp.html and www.eia.doe.gov/emeu/international/energyconsumption.html, except for Canadian GDP from Statistics Canada.

Figure 3.4

Relationship Between Total Primary Energy Supply (TPES) and GDP (adjusted for PPP)

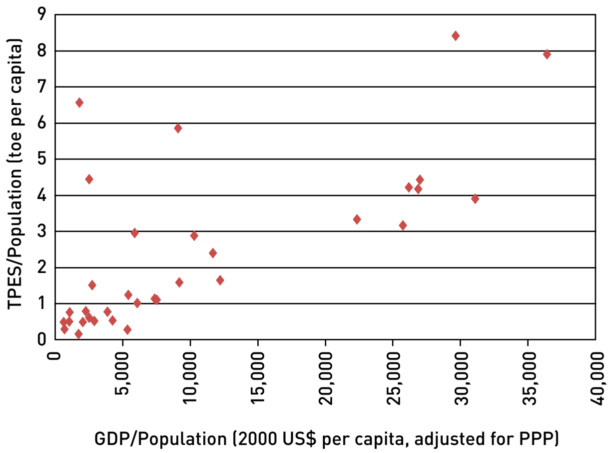


SOURCE: Based on data from the International Energy Agency, Key World Energy Statistics 2006, *Paris, France, 2006, accessed at www.iea.org/textbase/nppdf/free/2006/key2006.pdf, pp. 48–57.*

[22] Based on data from the International Energy Agency, *Key World Energy Statistics 2006*. Total primary energy supply (TPES) per capita in the US is approximately 7.91 tonnes of oil equivalent, compared with average world TPES per capita of 1.77.

Figure 3.5

Relationship Between Per Capita Total Primary Energy Supply (TPES) and Per Capita GDP (adjusted for PPP)



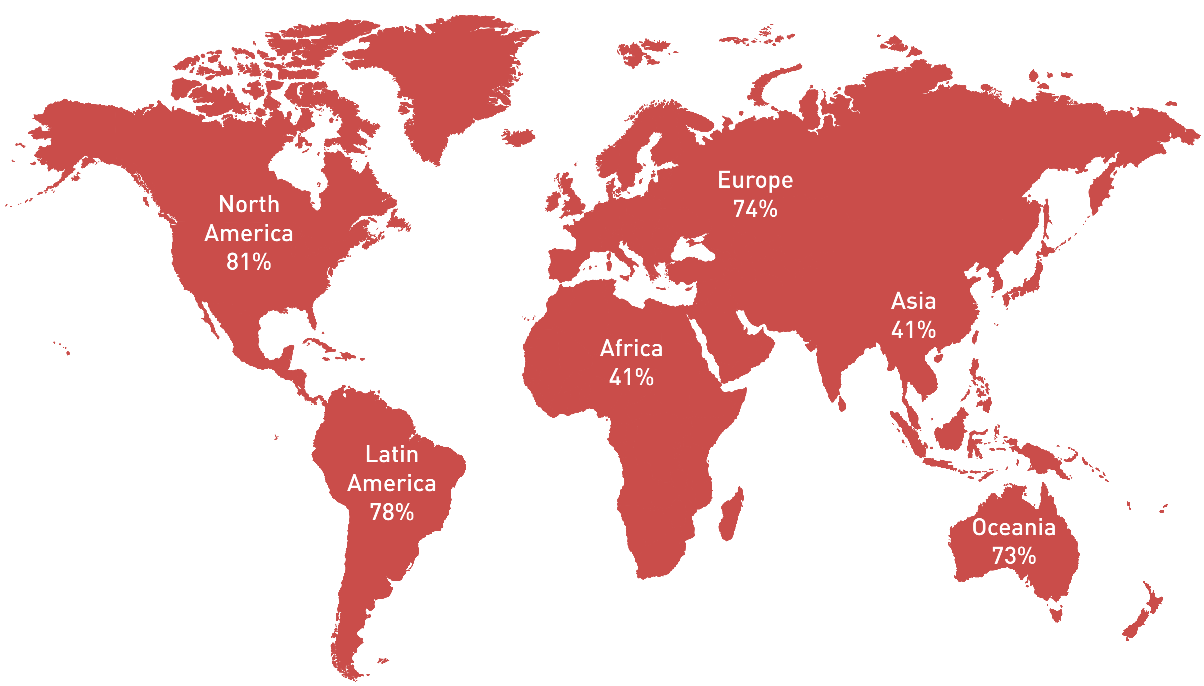
SOURCE: Based on data from the International Energy Agency, Key World Energy Statistics 2006*, Paris, France, 2006, accessed at www.iea.org/textbase/nppdf/free/2006/key2006.pdf*

Urbanization: Economic growth in many countries is associated with the urbanization of their populations. In some cases, urbanization has been very rapid. For example, in China in 1975 an estimated 17.4 percent of the population lived in urban areas. By 2005 this had increased to 40.5 percent, and the proportion is forecast to increase significantly.[23] Urban population growth has implications for both the amount and type of energy demanded. Typically, urban populations are less able to rely on biomass (such as wood or animal waste) and are more dependent on fossil fuels and electricity. This reliance on different energy forms is partly driven by transportation (favouring fuels that are easier to transport) and as urban areas become larger, may be driven by requirements to burn cleaner fuels. In more developed nations, suburban development often increases the need for personal transport.

In Figure 3.6 we present average rates of urbanization by region. It is significant that Asia and Africa are relatively less urbanized than the rest of the world.

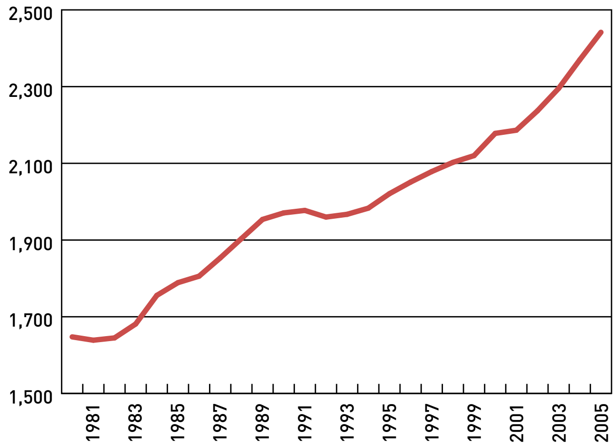
Figure 3.6

Urbanization Rate by Region, 2003



[23] United Nations Development Programme, *Human Development Report 2006*, *Beyond scarcity: Power, poverty and the global water crisis, 2006*. For purposes of comparison, North America currently has an urbanization level of approximately 81 percent.

Figure 3.7
Per Capita World Electricity Consumption, 1980–2004 (kilowatt hours)



SOURCES: US Energy Information Administration, International Energy Outlook, *accessed at www.eia.doe.gov/ieo/elec.html (Table 6.2), www.eia.doe.gov/pub/international/iealf/table62.xls, and www.census.gov/ipc/www/idb/worldpop.html.*

Urbanization is also associated with electrification. While electricity consumption has been growing consistently (see Figure 3.7), there are large populations in the developing world, including in urban areas, without access to electricity.

Industrialization: In addition, energy demand and economic growth are historically linked to industrialization. The speed at which developing nations move toward a more industrial society, and which route they take to supply this society with energy, have important implications for both the speed at which growth is likely to take place and the consequent impact on the environment. In developed economies, manufacturing sectors are stable or declining, with increases in the level of activity in the service sector. This has implications for energy demand, since service sector growth is more likely to be reliant on electricity (for lighting, air conditioning, computers, and other electrical equipment) than it is on primary fuels.

In addition, energy demand and economic growth are historically linked to industrialization.

Affluence: Increasing economic activity is also accompanied by higher average incomes. Higher average incomes are associated with increased consumption of goods that expend more energy. In Figure 3.8 we present changes in per capita car ownership; the differences among regions of the world are striking. In developed economies other than the United States, the link between car ownership and per capita consumption is quite clear. Passenger car ownership has been falling in the United States even though total vehicle ownership has been rising. This is due to many Americans opting for sport utility vehicles, minivans and other light trucks which, by definition, are not passenger cars. World consumption of electricity is increasing more rapidly than total energy supply, residential demand being driven by large appliances in the 1980s (dishwashers and refrigerators) and more recently by smaller, computer chip-based home electronics.

3.1.3 Energy Intensity

The link between economic activity and energy is summarized by a measure of *energy intensity:* the amount of energy required to produce one dollar of economic activity. Industries characterized by low energy intensity may experience high rates of growth even if energy supply becomes more constrained. The lowering of energy intensity will generally reduce the environmental impact associated with rising output.

In general, the energy intensity of developed nations has been declining since the 1970s. This is due to technological advancement, improved efficiency, and a shift away from energy-intensive sectors. In Figure 3.9 we show a measure of energy intensity across groups of nations. The gap between the countries that once comprised the Soviet Union and its allies, although narrowing, is considerable.

Key drivers for lowering energy intensity in these economies are seen as further enterprise restructuring and power sector reform, including reforms in the way energy is priced.[24]

Although energy intensity is related to efficiency, high energy intensity does not necessarily imply poor energy efficiency. Energy intensity reflects both efficiency and underlying socio-economic conditions. A cold climate

Figure 3.8

Car Ownership, Number of Passenger Cars per 1000 Persons, 1990 and 2003 (passenger cars per person)

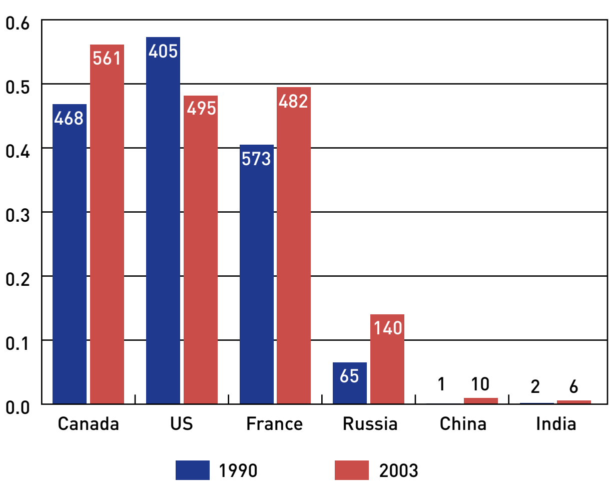
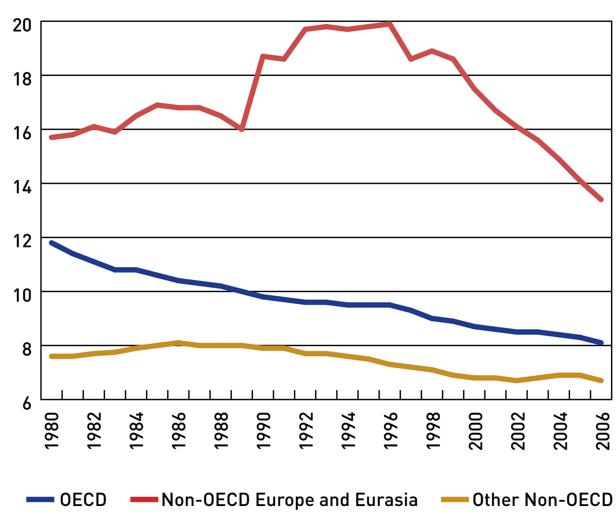


Figure 3.9

Energy Intensity in Various Regions, 1980–2006 (thousand Btus per US dollar of GDP)



SOURCE: US Energy Information Administration, International Energy Outlook, *2007, Figure 24.*

[24] J. Conrille and S. Frankhauser, *The Energy Intensity of Transition Economies,* European Bank for Reconstruction and Development, 2002.

contributes to higher energy use, as does reliance on road and air transportation, particularly in countries with dispersed populations. Given these factors, it is perhaps not surprising that Canada's energy intensity is second highest among the Organisation for Economic Co-operation and Development (OECD) nations, trailing only Iceland.[25]

In developed nations some of the reductions in energy demand from technological improvements have been outweighed by increased consumption. For example, the energy efficiency of car travel (the amount of energy required to travel one kilometre) improved by about 10 percent in developed nations between 1974 and 1998. However, over the same period, car use increased much more, resulting in an overall net increase in annual energy demand per vehicle.[26]

In some developing nations, declining energy intensity has accompanied rapid economic growth. For example, by 2004 energy intensity in China had declined 61 percent since 1980. Over this period, statistics on the EIA web site place China's average economic growth rate at 9.5 percent per year, while annual growth in energy use averaged 5.2 percent.

3.2 Historical Energy Consumption Patterns

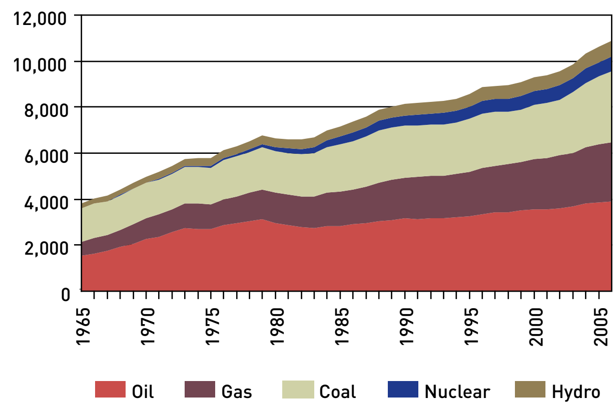
In this section we consider how the demand for energy has changed over the last few decades. This review limits the definition of primary energy to traded commodities (ignoring such fuels as peat and wood, largely because of data limitations).

Figure 3.10 shows total energy consumption by primary energy source. The demand for all forms of primary energy has increased over the past 40 years. For some forms of energy, this increase has been dramatic. Nuclear power, a negligible contributor to total energy consumption in 1965, now provides for 6 percent of world energy needs. In contrast, although coal has been a major source of energy throughout this period, its growth has been relatively modest.

However, Figure 3.11 shows huge variation in primary energy mix. Consumption in the Middle East is almost entirely based on oil and natural gas. South and Central American countries have by far the largest proportion

Figure 3.10

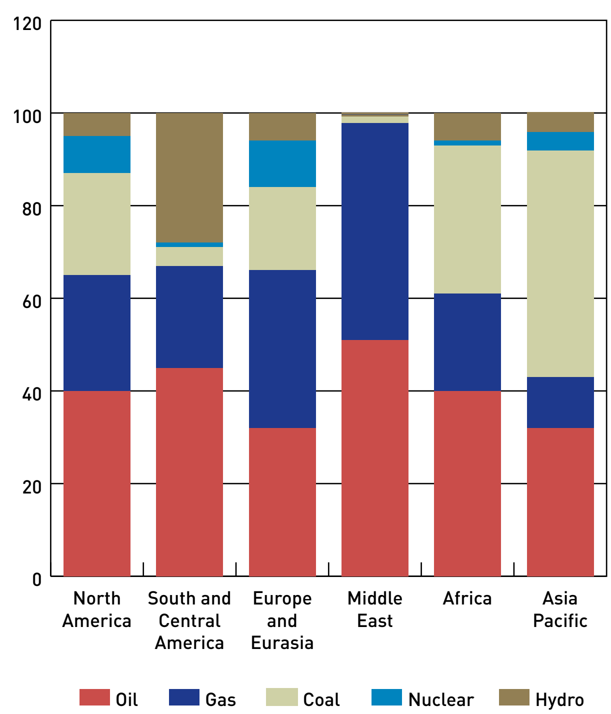
World Consumption of Primary Energy, 1965–2006 (million tonnes of oil equivalent per year)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

Figure 3.11

Regional Consumption of Primary Energy by Fuel (percent)



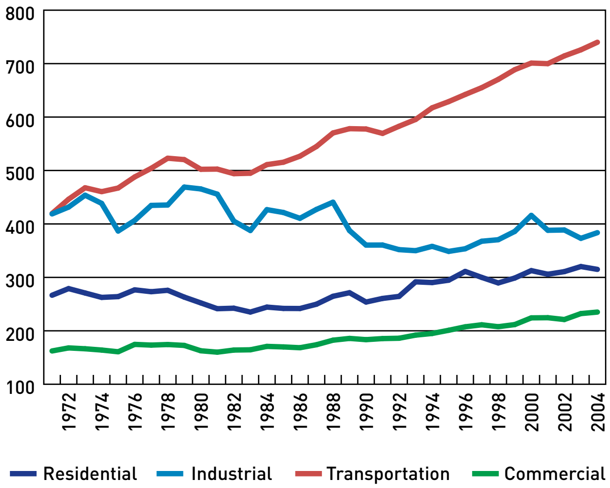
SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

[25] www.oecd.org/dataoecd/20/40/37551205.pdf

[26] Based on data for the IEA-11 presented in International Energy Agency, *Oil Crises and Climate Change: 30 Years of Energy Use in IEA Countries,* Brussels, Belgium, 2004.

Figure 3.12

North American Energy Consumption by End Use, 1971–2004 (million tonnes of oil equivalent per year)



SOURCE: IEA Statistics, Extended Energy Balances *(OECD North America), accessed electronically via Source OECD.*

of demand supplied by hydroelectricity. Coal remains the dominant energy source in the Asia Pacific area. In North America, Europe, and Eurasia the energy sources are more diverse, with nuclear energy being more prominent. Even more dramatic comparisons are possible when comparing energy consumption between countries. For example, in Norway 33.1 percent of primary energy demand is supplied by hydroelectric power. In contrast, only 1.9 percent of primary energy demand in France is supplied by hydroelectric power, with nuclear power supplying 42.5 percent.

As energy demand has increased, the choice of fuel source to supply the increase has in part been governed by relative prices.

Historical energy demand and the mix of primary sources tell only part of the story. As energy demand has increased, the choice of fuel source to supply the increase has in part been governed by relative prices. Government policy favouring particular energy forms has also been important, as has local and global public perception of environmental impact.

The ability of demand to be satisfied easily by alternative fuels is, in part, a story of technology. Some industrial users are able to switch fuels relatively quickly, allowing them to take advantage of differences in the relative cost of natural gas and fuels derived from crude oil. Demand for electricity can be satisfied using oil, natural gas, coal, nuclear, or hydro as the primary energy source, although in many cases short-term switchability is limited. Even in transportation, now highly reliant on oil, it may become possible to switch to alternative energy sources as technology advances.

Figure 3.12 illustrates the growth in the consumption of energy in North America in various end uses. Growth has been most rapid in the transportation sector, in marked contrast to trends in the residential and industrial sectors.

3.2.1 Consumption of Oil

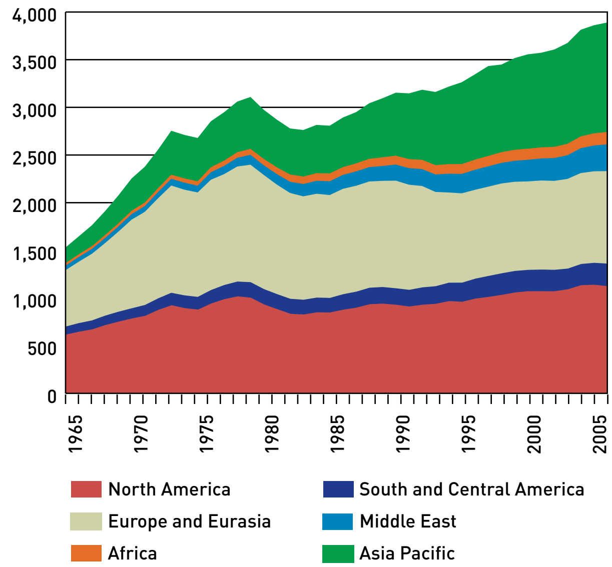
In Figure 3.13 we illustrate the historical consumption of oil in different areas of the world. Historically, oil consumption displays an overall upward trend, with two periods of decline in the early and late 1970s. Both declines correspond to periods of high prices that prompted reductions in consumption and switching to alternative fuels. The first period corresponds to the dramatic increase in the price of oil that occurred in 1973 following the Arab oil embargo (the price of Arabian Light increased from US$1.85/barrel to $11.54 in 1974). Oil prices again peaked in 1981, rising to a high of nearly US$40/ barrel following the Iranian Revolution.

On a per capita basis North America consumes more oil than any other continent, accounting for 29 percent of estimated global oil demand in 2006.[27] Oil consumption in the transportation sector currently represents two-thirds of total US oil demand,[28] consisting of gasoline, jet fuel, and diesel — the lighter components of the crude barrel. In Canada, transportation accounts for just over half of the demand for refined petroleum products.[29] In both countries the transportation share is expected to continue to increase as oil use declines in other sectors. In the US, the transportation sector is 96 percent dependent on petroleum, accounting for 28 percent of the country's total energy consumption, and producing one-third of its CO_2 emissions. Demand growth for oil in North America is focused on lighter-end gasoline and diesel. This poses a challenge to refineries to invest in upgrading/conversion facilities so as to maximize their flexibility to process a diverse (and increasingly heavy) crude slate while satisfying demand for a lighter cut of the barrel.

While North America's share of oil demand is large, most of the growth in world oil demand has come from the rapidly expanding Asia Pacific economies. Over the period 1965 to 2006, oil consumption in these nations increased by 597 percent. Over the same period, North American oil consumption rose 82 percent. As can be seen from Figure 3.13, demand growth in Asia has been strong over several decades.

Figure 3.13

Oil Consumption by Region, 1965–2006 (million tonnes per year)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

3.2.2 Consumption of Natural Gas

Natural gas has a long history as a source of fuel. In Figure 3.14 we compare the historical consumption of natural gas by region. The demand for gas has increased more rapidly than the demand for oil, with growth most pronounced in Europe and Eurasia. Demand growth in North America has been relatively modest, and while growth elsewhere in the world has been rapid, it represents a small proportion of gas use. These broad regional trends hide wide differences between countries and within regions. These differences arise, in part, because market penetration by natural gas requires sufficient pipeline infrastructure to deliver large quantities of gas to final consumers.

The relatively modest growth in North American demand from 1973 onward contrasts with the very rapid increase in gas consumption in earlier decades as the United States pipeline infrastructure was built.

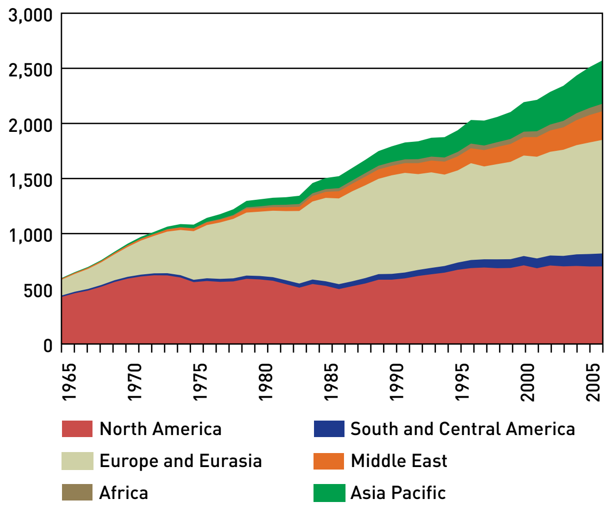
[27] British Petroleum Company, *BP Statistical Review of World Energy 2007,* London, United Kingdom, 2007.

[28] US Energy Information Administration, *Annual Energy Review*, *2004*, accessed at www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/petflow

[29] Statistics Canada Catalogue No. 57-003-XIE, accessed at www.statcan.ca/english/freepub/57-003-XIE/2005000/t003_en.htm

Figure 3.14

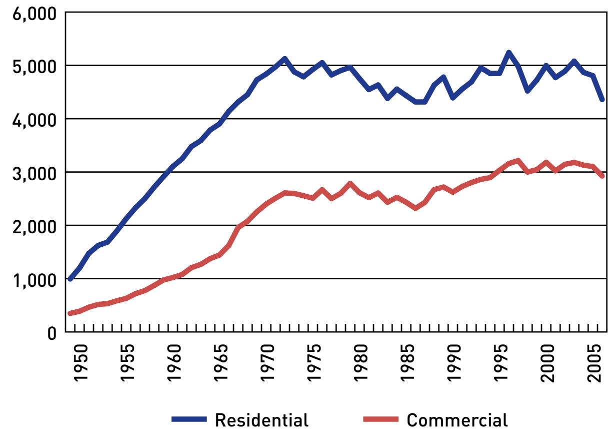
Consumption of Natural Gas by Region, 1965–2006 (million tonnes of oil equivalent per year)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

Figure 3.15

Residential and Commercial Gas Consumption in the United States, 1949–2006 (billions of cubic feet per year)



SOURCE: US Energy Information Administration, accessed at http://tonto.eia.doe.gov/dnav/ng/hist/n3010us2A.htm and http://tonto.eia.doe.gov/dnav/ng/hist/n3020us2A.htm

This is evident from the historical residential and commercial demand in the United States from 1930 to the present, shown in Figure 3.15.

The capped gas prices in the early 1970s led to pronouncements of an end to natural gas supply and policies to disconnect residential and commercial users from the gas distribution system. The gradual deregulation of prices led to new supplies and renewed interest in gas as a source for space heating. Even during the post 1970s era, the increased gas prices remained below equivalent electricity prices in the United States.

In the past the long-term drivers for natural gas demand have been different in each sector of the economy. In the *residential sector*, space heating for new homes has been a strong driver for demand. Although efficiency of furnaces has improved, increasing size of new homes has offset the resulting decreasing demand per square foot. In the *industrial sector*, switching of industrial process from coal and petroleum to natural gas has driven increasing demand for natural gas, but in recent years the high price of natural gas has driven many gas-intensive industries such as petrochemicals from the United States to locations where less expensive gas is available. Industrial consumption of natural gas in the United States was lower in 2004 than in any year over the period 1989–2003.

Gas-fired *electricity generation* is proving a major source of demand in some countries. The attractiveness of gas-fired generation is that it can be built at both a small and large scale (as opposed to coal and nuclear options, which are limited to larger-scale developments). Gas-fired generation is also attractive in that it can be turned on and off to meet peak electricity demands. Natural gas use in *transportation* has accounted for only a very small share of total demand. Estimates indicate approximately 130,000 natural gas vehicles in the US and approximately 2.5 million worldwide.[30] The major gas use in the transportation sector continues to be compressor fuelling for pipeline transportation.

3.2.3 Consumption of Electricity

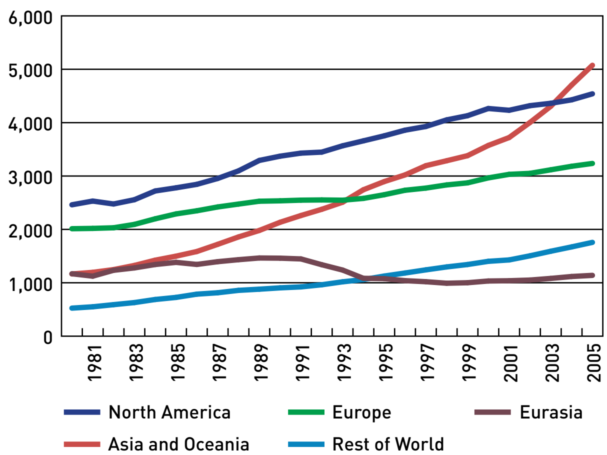
Electricity consumption has increased steadily for over 100 years. However, on all continents there are still homes that are not connected to an electricity grid. The differences between groups of countries are clear. Growth in electricity consumption has been strong except in Europe and Eurasia.

It is noteworthy that until the early 1970s, electricity consumption in North America was encouraged by promotional tariffs. The justification for this was to

[30] The Natural Gas Vehicle Coalition, cited at www.naturalgas.org/overview/uses_transportation.asp

exploit economies of scale. Since then, despite widespread price hikes and efforts to promote electricity conservation prompted by rising supply costs, consumption continues to grow. This is illustrated in Figure 3.16.

Figure 3.16
Regional Electricity Consumption, 1980–2005 (terawatt-hours)



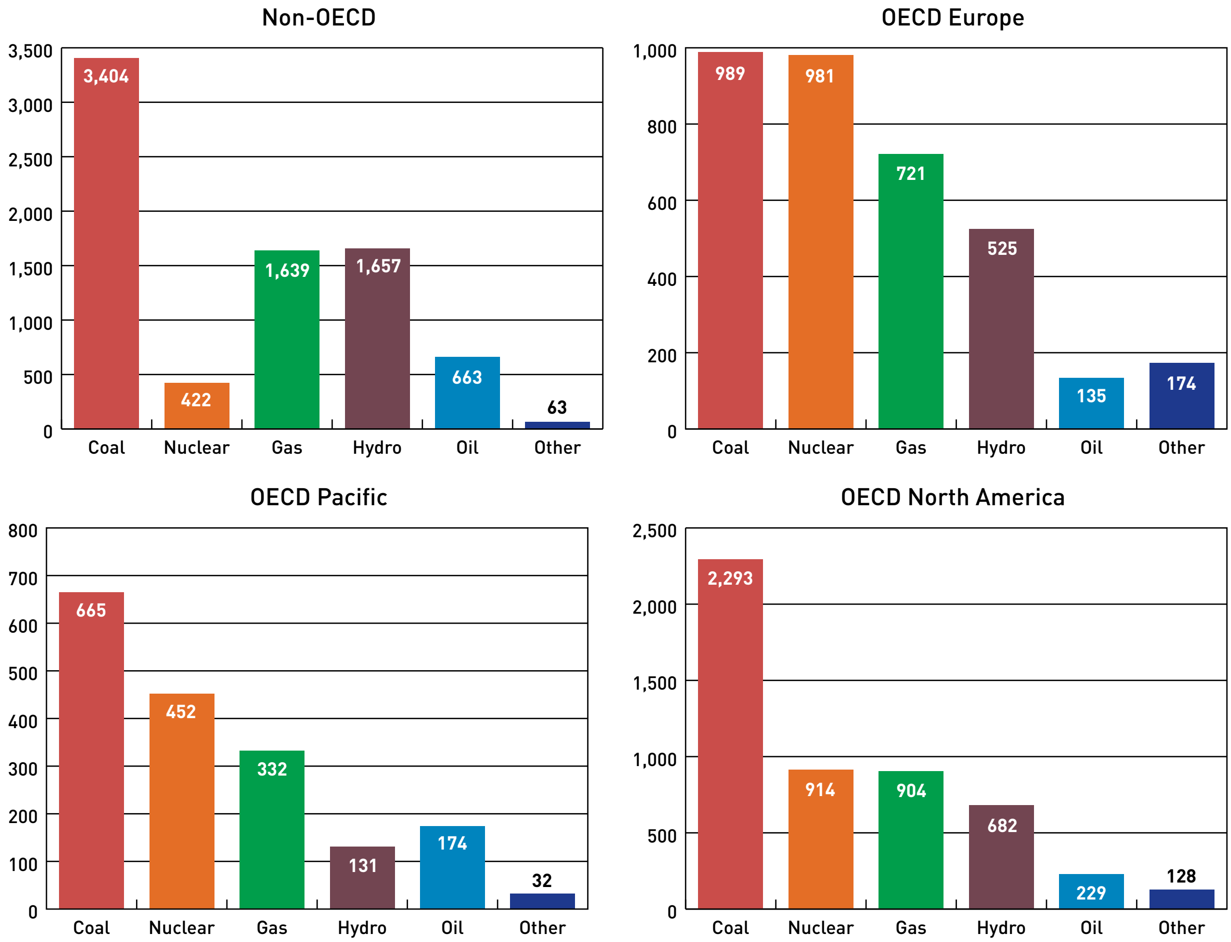
SOURCE: US Energy Information Administration, accessed in September 2007 at www.eia.doe.gov/emeu/international/electricityconsumption.html

There are marked differences geographically in the mix of technologies used to produce electricity. Coal accounts for 40 percent of global electricity generation. It is the dominant fuel in the Pacific and in the United States. Natural gas supplies an additional 20 percent while hydro and nuclear power are almost equally important for world-wide electricity generation, at 16 percent each. Oil supplies only 7 percent, and non-hydro renewables, 2 percent. The mix of energy sources in each service area is influenced by the temporal nature of the demand for electricity (the load curve) and by the economics of power generation (i.e. capital and running costs of each generation type). The resulting pattern is illustrated in Figure 3.17.

3.3 Energy Consumption: A Summary Comment

Population growth, economic development, and energy intensity have been the most important determinants of energy demand in the past, and will continue to be in the future. With population numbers expanding at significant rates in the developing world, and economic growth proceeding as well, the outlook is for increasing energy consumption in the foreseeable future. The mix of energy needed is likely to shift over time, as it has in the past.

Figure 3.17
Primary Energy Sources for Power Generation by Region, 2005 (terawatt-hours)



SOURCE: International Energy Agency, Electricity Information 2007, *Paris, France, 2007.*

The ultimate desired mix of energy sources will depend to some extent on how consumers value the services of energy as compared to environmental sustainability.

We do not, in general, desire energy for its own sake; we desire it for the services it provides — heat, cooling, power, light — all the things that make our lives easier. That means that the ultimate mix of energy uses is only one factor in determining the mix of primary energy employed. Transportation needs will keep oil in demand through the middle of this century, because alternatives are not likely to emerge on a large scale before then. Natural gas will grow in importance because we have an associated goal of lower emissions than those produced by other fossil fuels, and in the short term gas helps meet that goal. That characteristic may boost our interest in nuclear as well, particularly as knowledge about the real risks and costs of that source becomes more widely disseminated. Renewable sources are admired, but in the past have been limited by a lack of willingness to pay the needed premium for them. The ultimate desired mix of energy sources will depend to some extent on how consumers value the services of energy as compared to environmental sustainability.

4 HISTORICAL
Energy Supply

4.1 Energy Supply Sources

Prior to the Industrial Revolution of the 1800s, per capita energy use was very low. Biomass (primarily wood), beasts of burden, and slaves provided the needed energy. Coal became the driver of the Industrial Revolution and rapidly displaced wood as the most commonly used fuel. Techniques developed in the mining of gold, silver, copper, and other minerals were applied for the extraction of this resource. With the invention of the internal combustion engine, oil consumption grew until it in turn displaced coal as the world's largest source of energy. As civilization advanced, energy consumption increased exponentially. The human population energy consumption in 2000 was more than five times larger than in 1950, and more than 13 times as much as in 1900.[31] In the year 2005,[32] human population energy consumption was more than 15 times as large as in 1900.

The "modern" oil and gas industry had its beginnings in the 19th century. Natural gas was first used for street lighting as early as 1821, when it was piped through hollow logs to Fredonia, New York. However, it was not until the end of the century that gas was used more widely, when better drilling techniques and less leaky pipes were developed. The demand for better lighting led directly to the first widespread use of crude oil. By the 1850s, the best available lamp oil was selling for US$2.50 per gallon (US$0.60 per litre).

The first "oil boom" was unleashed when "Colonel" Edwin Drake found a practical way to produce large quantities of oil when he used a cable-tool drilling rig to tap an oil reservoir at Oil City, Pennsylvania, in 1859. By that time oil was already being produced from hand-dug wells in Canada and Eastern Europe; however, Drake's mechanically-drilled well is often cited as the beginning of the modern oil era. Initial development over the next four decades focused on the making and selling of kerosene for lighting.

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[31] Arlie M. Skov, SPE, Journal of Petroleum Technology, *World Energy Beyond 2050*, January 2003. Table 1 shows 1900 consumption equivalent to 14 million barrels of oil per day (MMbbl/d), 1950 at 35 MMbbl/d, and 2000 at 190 MMbbl/d.

[32] (10,537 Mtoe * 7.33)/365 = 216 million barrels per day. See British Petroleum Company, *BP Statistical Review of World Energy 2007,* London, United Kingdom, 2007.

The development of the internal combustion engine late in the 19th century transformed society and changed the nature of the oil and gas industry. The diesel engine, invented in 1892, became popular for industrial machinery and ships in the early 1900s. In his capacity as First Lord of the Admiralty, Winston Churchill made a crucial decision prior to World War I to switch Britain's Imperial Navy from coal to oil.

Fossil fuels continue to dominate global primary energy supply. They represented 89.2 percent of total primary energy supply in 1986 and 88.6 percent in 2006, as illustrated in Figure 4.1.

Fossil fuel's share of global primary energy production declined over this 20-year period, but the rate of decline has been slow. Oil and coal have both experienced a decrease in share; natural gas and nuclear have both seen an increase; and hydroelectricity's share has held at 6 percent. Growth rates for each are presented in Table 4.1. Nuclear energy and natural gas have achieved the highest growth rates.

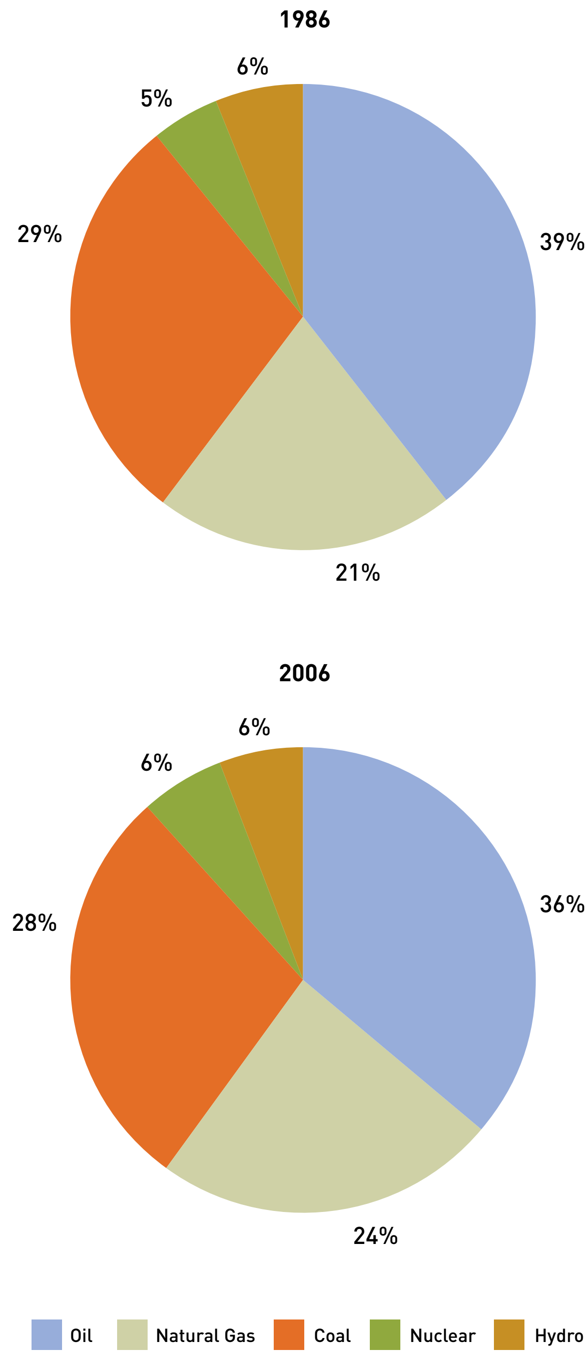
It is notable that the highest growth rates have been achieved by nuclear energy and natural gas, although nuclear started from a smaller base.

Table 4.1
Growth in Global Primary Energy Supply, 1986–2006

Energy Source	Average Annual Growth (%)
Oil	1.4
Natural Gas	2.5
Coal	1.7
Nuclear	2.7
Hydroelectricity	1.6
Total	**1.8**

SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

Figure 4.1
Global Primary Energy Production



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

4.2 Fossil Fuels

As observed, fossil fuels dominate global energy supply. The three major fossil fuels have all seen significant growth in production; the rate of growth has been the highest for natural gas.

4.2.1 Crude Oil

The British Petroleum Company (BP) estimated proven reserves of conventional crude oil at 1,207.8 billion barrels at year-end 2006.[33] However, oil is not uniformly distributed geographically; approximately 62 percent of the world's conventional crude oil reserves are located in the Middle East, as illustrated in Figure 4.2.

Organization of Petroleum Exporting Countries (OPEC)[34] member countries control much of the world's oil supply, holding 905.5 billion barrels of reserves, or 75 percent of the world total. Outside OPEC, significant reserves are held by Russia (79.5 billion barrels), Kazakhstan (39.8 billion barrels), the US (29.9 billion barrels), Canada (17.1 billion barrels), and China (16.3 billion barrels). However, while the US and China hold large reserves and are large oil producers, both are very significant and growing oil importers.

Canada's conventional oil reserves, as reported by BP, are 6.9 billion barrels. However, BP's estimate does not include oil from Alberta's massive oil sands deposits. The Alberta Energy and Utilities Board (AEUB) estimates the remaining established resources in the crude bitumen (oil sands) to be 173 billion barrels at year-end 2006. The *Oil & Gas Journal*[35] now recognizes these resources and places Canada in second position in the world, behind only Saudi Arabia. Canadian and Saudi reserves, thus defined, are illustrated in Figure 4.3.

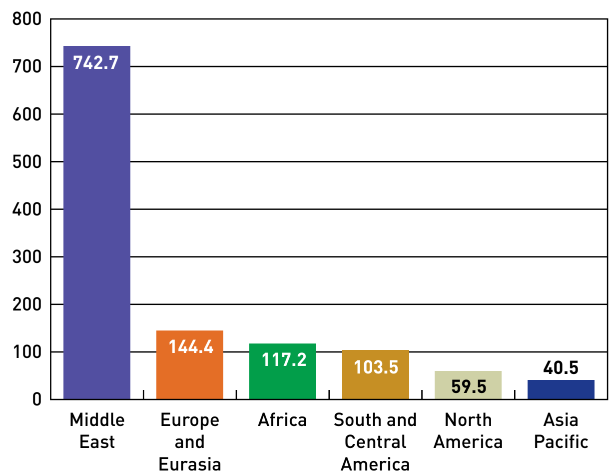
Alberta's oil sands are discussed further in Section 4.8.

While OPEC countries control almost 75 percent of the world's oil reserves, they have not achieved an equivalent market share.

Prior to 1977 (see Section 4.6), OPEC generated approximately 50 percent of world oil production. However, the oil price increases that followed the Yom Kippur War in 1973 and the Iranian Revolution

Figure 4.2

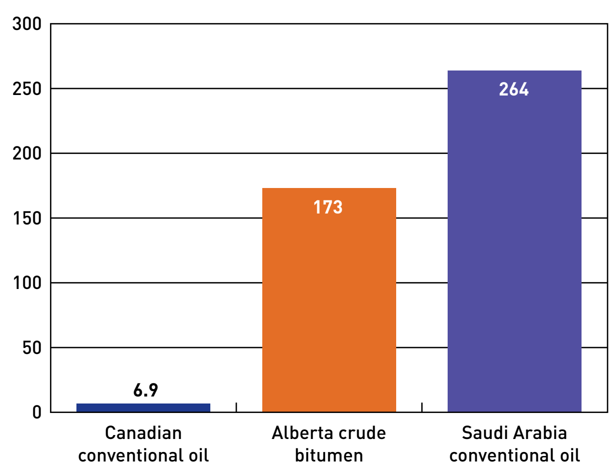
Regional Proved Oil Reserves at Year-End 2006 (billion barrels)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

Figure 4.3

Canadian and Saudi Oil Reserves at Year-End 2006 (billion barrels)



SOURCE: Alberta Energy and Utilities Board, Energy Reserves 2006 and Supply/Demand Outlook 2007–2016, *Calgary, Alberta, Canada, June 2006.*

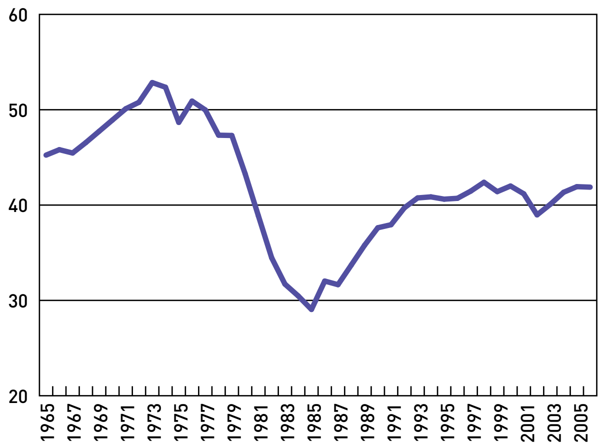
33 These estimates did not include Canada's oil sands, discussed below.

34 OPEC members: Middle East (Iran, Iraq, Kuwait, Qatar, Saudi Arabia, United Arab Emirates), North Africa (Algeria, Libya). West Africa (Nigeria), Asia Pacific (Indonesia), South America (Venezuela).

35 Future Energy Supply, *Oil & Gas Journal,* Vol. 101, Nos. 27–32, 2003.

Figure 4.4

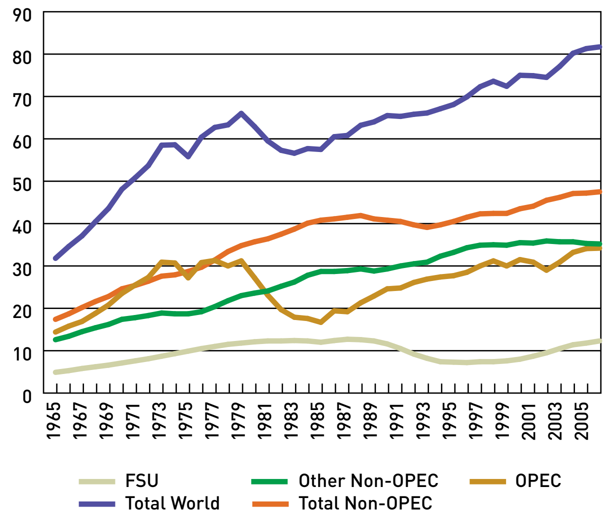
OPEC Market Share (percent)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

Figure 4.5

Regional and Total World Oil Production, 1965–2006 (millions of barrels per day)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

in 1979–1980 dampened world demand for crude oil and encouraged development of new, non-OPEC supply. OPEC was forced to curtail production to support prices and maintain adequate oil revenues, thus confirming its status as the world's "swing" producer. This is illustrated in Figures 4.4 and 4.5.

World oil production, including crude bitumen, synthetic crude oils, and natural gas liquids, reached 81.6 million barrels per day in 2006.

OPEC countries have seen some production growth over the last 20 years, after major declines following the two oil price shocks mentioned earlier in this section. However, the OPEC producers' share has never regained its peak of 1973.

Table 4.2

Growth in Global Crude Oil Supply, 1986–2006

Region	Average Annual Growth (%)
OPEC	2.7
Non-OPEC	0.9
Former Soviet Union	-0.05
Total World	**1.4**

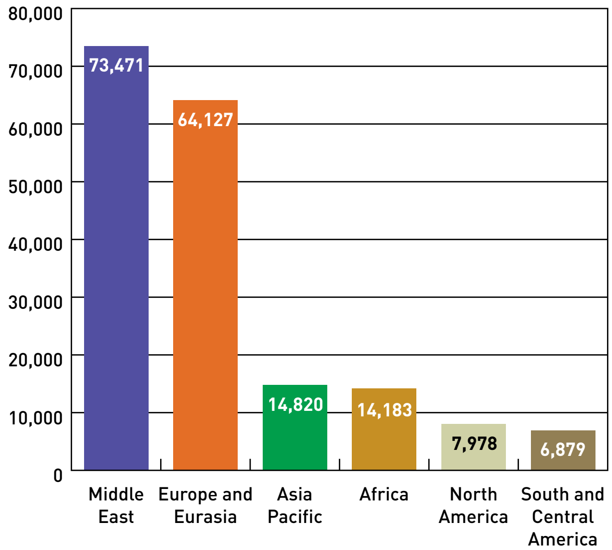
SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

Non-OPEC producers outside the former Soviet Union (FSU) have also achieved production growth. FSU countries[36] experienced severe declines following the break-up of the Soviet Union; however, Russian production is now recovering, and strong growth is also being achieved in Kazakhstan. Regional growth figures for the last 20 years are shown in Table 4.2.

[36] Former Soviet Union: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

Figure 4.6

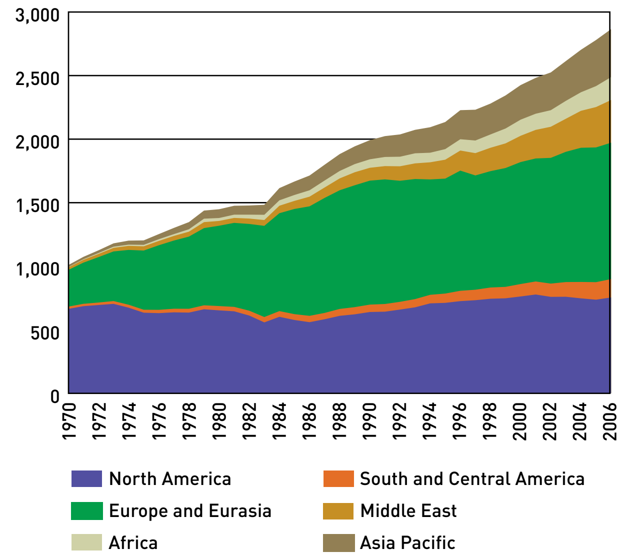
Regional Proved Natural Gas Reserves at Year-End 2006 (billion cubic metres)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

Figure 4.7

Regional Natural Gas Production, 1970–2006 (billion cubic metres per year)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

4.2.2 Natural Gas

BP estimated proven reserves of natural gas in the world at 6,405.5 trillion cubic feet (181.5 trillion cubic metres) at year-end 2006. This is 1,067.5 billion barrels of oil equivalent at 6:1 (i.e. assuming 6,000 standard cubic feet of natural gas is equivalent to one barrel of crude oil). On this basis, natural gas reserves represent 88.3 percent of total conventional oil reserves.

Natural gas is more evenly distributed throughout the world than crude oil. The largest gas reserves are located in the FSU (Europe and Eurasia)[37] and the Middle East, as illustrated in Figure 4.6.

Since it is relatively expensive to transport natural gas over long distances, gas markets tend to be more continental in nature than crude oil markets. For example, 73 billion standard cubic feet per day (Bcfpd) of natural gas were produced in North America in 2006. Of this total, approximately 0.16 Bcfpd were liquefied and shipped to Japan as liquefied natural gas (LNG), the remainder consumed on the continent. North American natural gas production was supplemented by approximately 1 Bcfpd of natural gas as LNG, mostly from Trinidad and Tobago. Historical gas production is illustrated in Figure 4.7.

Figure 4.7 illustrates that, while growth in total North American, European, and Eurasian natural gas production has been relatively modest, strong production growth has occurred in other regions. Regional growth rates are summarized in Table 4.3.

4.2.3 Coal

The world's coal reserves are substantial and are distributed much more uniformly than either oil or natural gas reserves. BP estimates proven reserves of coal to be 908.5 billion tonnes at year-end 2006. The distribution of these reserves and the share of anthracite and bituminous coal of each region (shown in brackets) are illustrated in Figure 4.8.

[37] Europe and Eurasia countries: include Europe and Former Soviet Union. Europe: includes European members of OECD (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Republic of Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, UK) and non-OECD countries (Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Former Yugoslav Republic of Macedonia, Gibraltar, Malta, Romania, Serbia and Montenegro, Slovenia).

Figure 4.9 illustrates that European and Eurasian coal production has declined dramatically, while North American coal production has grown slowly (coal consumption is exhibiting a similar pattern in both regions). The largest growth has occurred in South and Central America and the Asia Pacific region respectively. Regional growth rates are summarized in Table 4.4.

Table 4.3

Growth in Global Natural Gas Supply, 1986–2006

Region	Average Annual Growth (%)
North America	1.4
South and Central America	5.2
Europe and Eurasia	1.1
Middle East	7.3
Africa	6.3
Asia Pacific	5.8
Total World	**2.5**

SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

Table 4.4

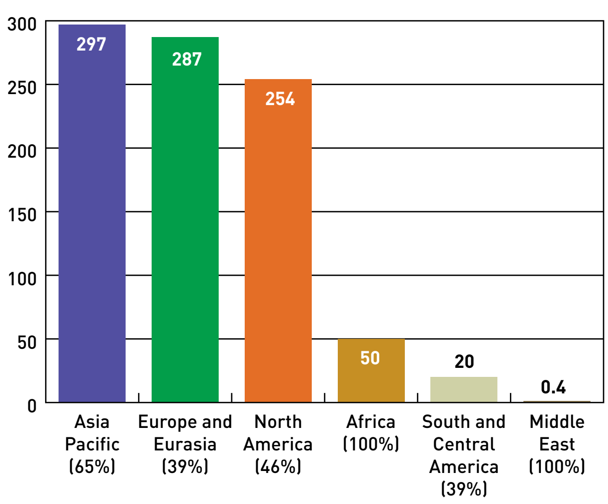
Growth in Global Coal Supply, 1986–2006

Region	Average Annual Growth (%)
North America	0.9
South and Central America	7.3
Europe and Eurasia	-2.8
Middle East	-0.9
Africa	1.6
Asia Pacific	4.7
Total World	**1.7**

SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

Figure 4.8

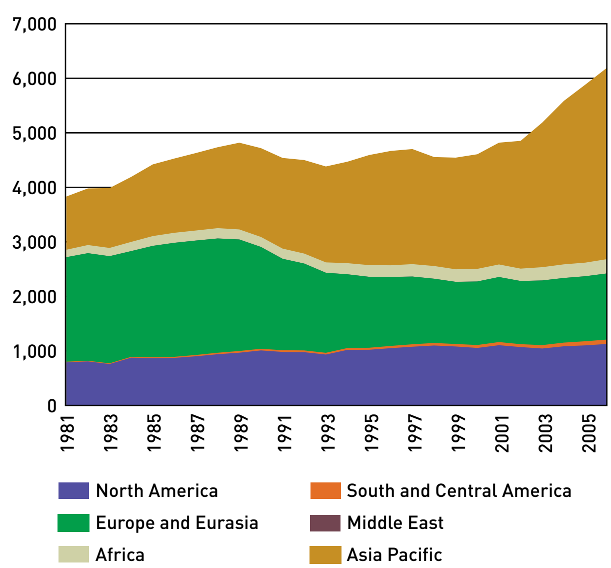
Regional Proven Coal Reserves at Year-End 2006 (thousand million tonnes)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

Figure 4.9

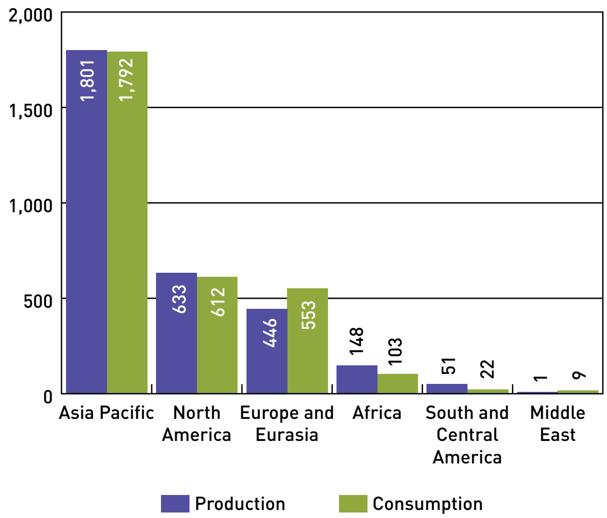
Regional Coal Production, 1981–2006 (million tonnes per year)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

Figure 4.10

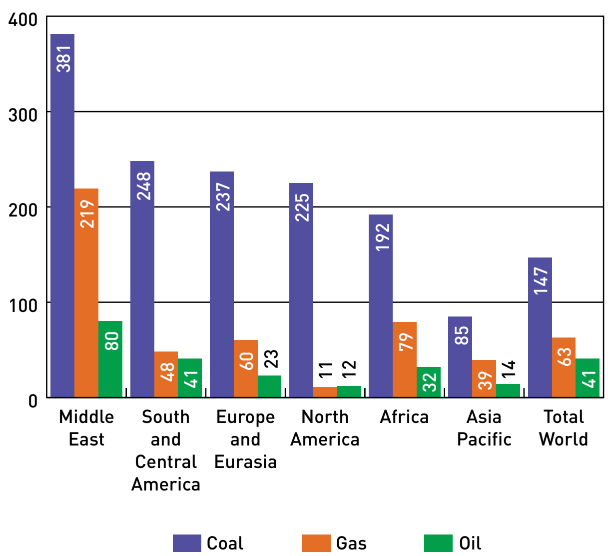
Regional Coal Production and Consumption, 2006 (million tonnes of oil equivalent)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

Figure 4.11

Regional Fossil Fuel Reserves/Production Ratios at Year-End 2006 (years)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

Intercontinental coal trade is limited; most coal is consumed relatively close to the source of supply, as illustrated in Figure 4.10.

Coal combustion results in substantial greenhouse gas (GHG) emissions and particulate emissions unless control technologies are applied. Advanced coal technologies exist that are capable of almost entirely eliminating particulate, oxides of nitrogen, and sulphur dioxide emissions from coal-fired power generation. Coal-fired power generation is increasingly efficient, resulting in less coal being used per unit of electricity generated. Thermal efficiencies of coal-fired power plants have reached 40 percent, with the prospect of further improvement to 50 percent and better. Reaching this target would achieve a reduction in GHG emissions of 10 to 20 percent compared to the best conventional plants today. Integrated Gasification & Combined Cycle technology (IGCC) offers the prospect of a steep improvement in thermal efficiency of coal use.

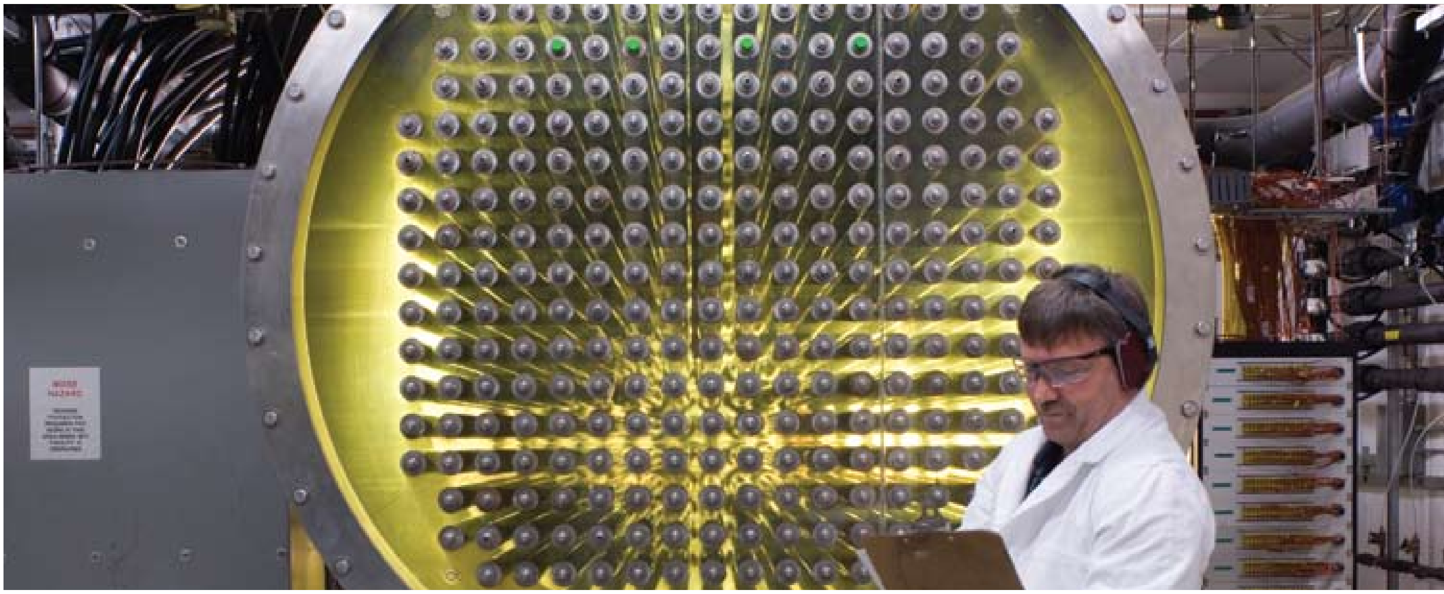
4.2.4 Fossil Fuel Reserves/Production Ratios

Reserves/production (R/P) ratios indicate the number of years required to deplete identified reserves at current production rates, assuming no new reserve additions. R/P ratios for fossil fuels are plotted in Figure 4.11.

R/P ratios for coal are more than 100 years in all regions of the world except Asia Pacific. There is considerable potential for increased coal utilization as long as the transportation and environmental challenges associated with using this resource can be overcome.

For natural gas, R/P ratios exceed 45 years in all parts of the world except North America, which is slightly less than 11 years.

R/P ratios for crude oil are almost 80 years in the Middle East and 40 years in Central and South America. The R/P ratio for crude oil in North America is approximately 12 years.

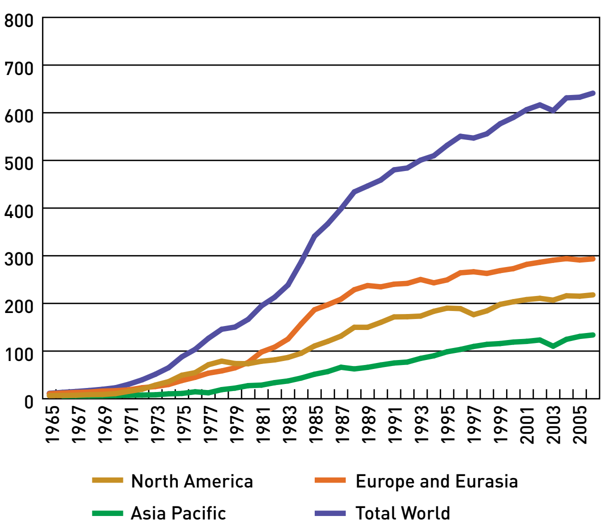


4.3 Nuclear

Nuclear became an important source of energy following the first oil price shock in 1973 (see Figure 4.12). The main reasons for the rise of nuclear power are the low cost of fuel compared to other primary energy sources, and abundant uranium resources located in politically stable regions (see Figure 4.13). Total known recoverable uranium resources equal 4.7 million tonnes, half of which are found in Australia, Kazakhstan, and Canada. Canada is currently the largest manufacturer of uranium, producing about one-third of the world's total.

Figure 4.12

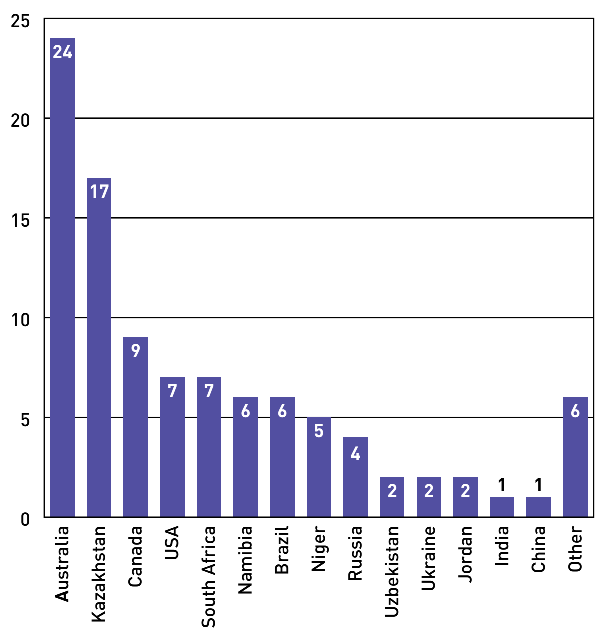
World and Regional Consumption of Nuclear Energy, 1965–2006 (million tonnes of oil equivalent per year)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

Figure 4.13

Country Shares Out of Total World Known Recoverable Uranium Resources (percent)

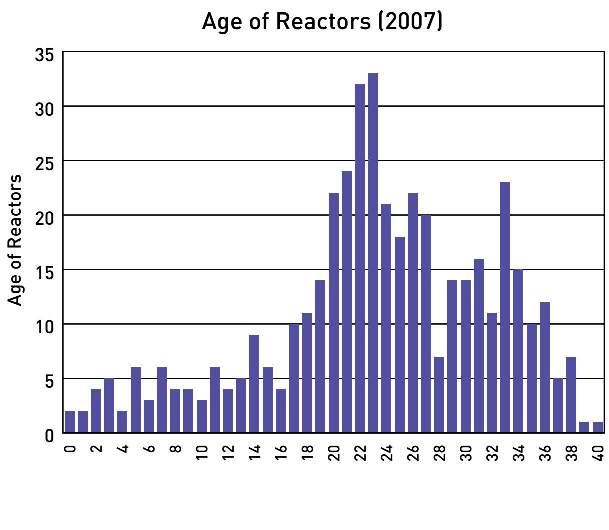


SOURCE: World Nuclear Association, accessed at www.world-nuclear.org/info/inf75.htm; March 2007 update.

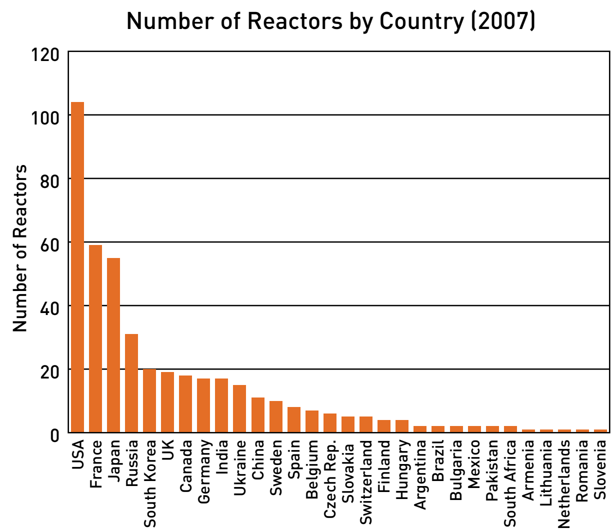
Figure 4.14 indicates that in 15 countries, nuclear's share exceeds 30 percent of total electricity generation. The same figure illustrates that the average age of reactors is around 20 years, and 100 reactors are more than 30 years old. In the recent past, the growth of nuclear has been concentrated in refurbishments and expansions of existing capacity, although new reactors are still being built.

The slower growth in nuclear power is likely a result of the two major incidents that have permeated the public consciousness: Chernobyl and Three Mile Island. Three Mile Island was a widely reported close call that did not have serious consequences. Chernobyl, on the other hand, was a serious incident that resulted in loss of life and has affected public attitudes toward nuclear power ever since. This accident was caused by the faulty design of the reactor's safety systems and the inadequacy of the reactor's control systems. It is nearly impossible for an accident such as what occurred at Chernobyl to occur in other reactors, given the design, control, safety and containment systems that are currently in use. Nonetheless, that accident caused negative perceptions about the safety of nuclear power that will take some effort to turn around.

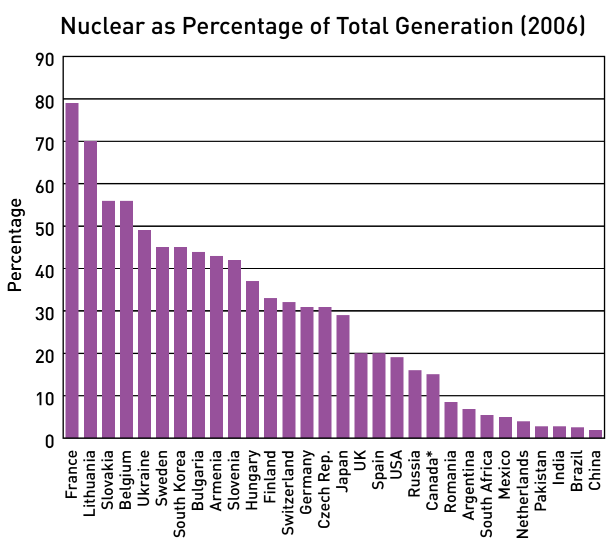
Figure 4.14
Nuclear Electricity Generation in the World



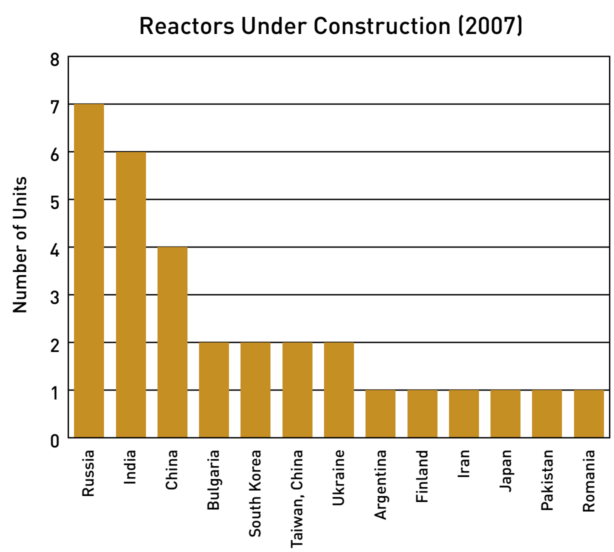
SOURCE: www.iaea.org/cgi-bin/db.page.pl/pris.agereac.htm



SOURCE: www.iaea.org/cgi-bin/db.page.pl/pris.reaopucct.htm



SOURCE: www.world-nuclear.org/info/reactors.htm



SOURCE: www.iaea.org/cgi-bin/db.page.pl/pris.charts.htm

Another factor that contributed to moderate growth in the nuclear industry over the past several decades was the competitive environment it faced from relatively low-cost hydrocarbon fuels. Oil and natural gas have had volatile price movements over that period, but their real price has remained low enough to allow them to be competitive with nuclear. This is partly because the costs associated with failing to address environmental issues were not as much of a concern in the past. Today, with the environment taking a higher profile, and with the cost of oil and natural gas at increasingly high levels, nuclear is becoming a strong competitive alternative.

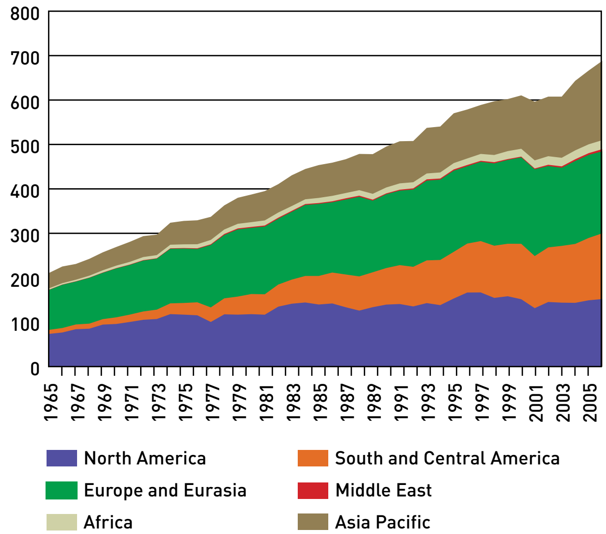
4.4 Hydroelectricity

Large-scale hydroelectricity generation is widespread throughout the world (see Figure 4.15). Hydro plants have low operating costs, long lives, and low emissions.

Contrary to popular perception, however, hydro power does not have zero emissions because methane is produced from the decomposition of plants in the flood areas. Several authors conclude that these emissions are orders of magnitude below those of fossil fuels; forming the rationale for excluding hydro from national tallies of greenhouse gas emissions.[38] A dissenting finding was reached by Vincent St. Louis et al.[39] who conclude, "Reservoirs are sources of greenhouse gases to the atmosphere and their surface areas have increased to the point where they should be included in global inventories of anthropogenic emissions of greenhouse gases"; they estimate that worldwide greenhouse gas emissions from reservoirs amount to about 7 percent of the global warming potential of other anthropogenic emissions. Other possible environmental impacts of hydroelectricity include damage to fish habitat and downstream water quality.[40] Bacteria present in decaying vegetation can also change mercury, present in rocks underlying a reservoir, into a form that is soluble in water. The mercury accumulates in the

Figure 4.15

Regional Consumption of Hydroelectricity, 1965–2006 (million tonnes of oil equivalent per year)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

bodies of fish and poses a health hazard to those who depend on these fish for food.[41] The high initial costs and environmental impacts are issues that need to be addressed for the development of large-scale hydro plants, as do reliability concerns, given the variability of rainfall in some regions. Climate change could potentially make hydroelectricity less reliable if it increases the severity and volatility of the weather.

In many areas of the world, notably Europe and North America, there is no room for expansion of hydroelectric power; nearly all of the available sites are in use already.

4.5 Other Renewable Energy Sources

Renewable energy is dealt with in Chapter 5. Over the past two decades, the share of renewable energy sources as a percentage of total primary energy has been relatively stable at around 13–14 percent. Although the growth rates of individual renewable sources have been startling (wind energy has grown 24 percent per year since 1990), the overall contribution has not increased in percentage terms because

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38 A. Tremblay & others, *The Issue of Greenhouse Gases from Hydroelectric Reservoirs: From Boreal to Tropical Regions.*

39 St. Louis, V. L. et al., "Reservoir Surfaces as Sources of Greenhouse Gases to the Atmosphere: A Global Estimate," *Bioscience,* Volume 50 No 9, September 2000, pp. 766–775.

40 International Energy Agency, *Hydropower and the Environment: Present Context and Guidelines for Future Action,* Volume I, May 2000, pp. 9–12.

41 World Bank, cited at www.worldbank.org/html/fpd/em/hydro/tp.stm

of the small base from which it started, and because of the very slow growth of hydro.

4.6 Oil and Geopolitics

The First World War — 1914–1918 — established oil as a key strategic commodity. Horses and trains gave way to tanks, trucks, airplanes, motorcycles, and automobiles — all powered by gasoline.

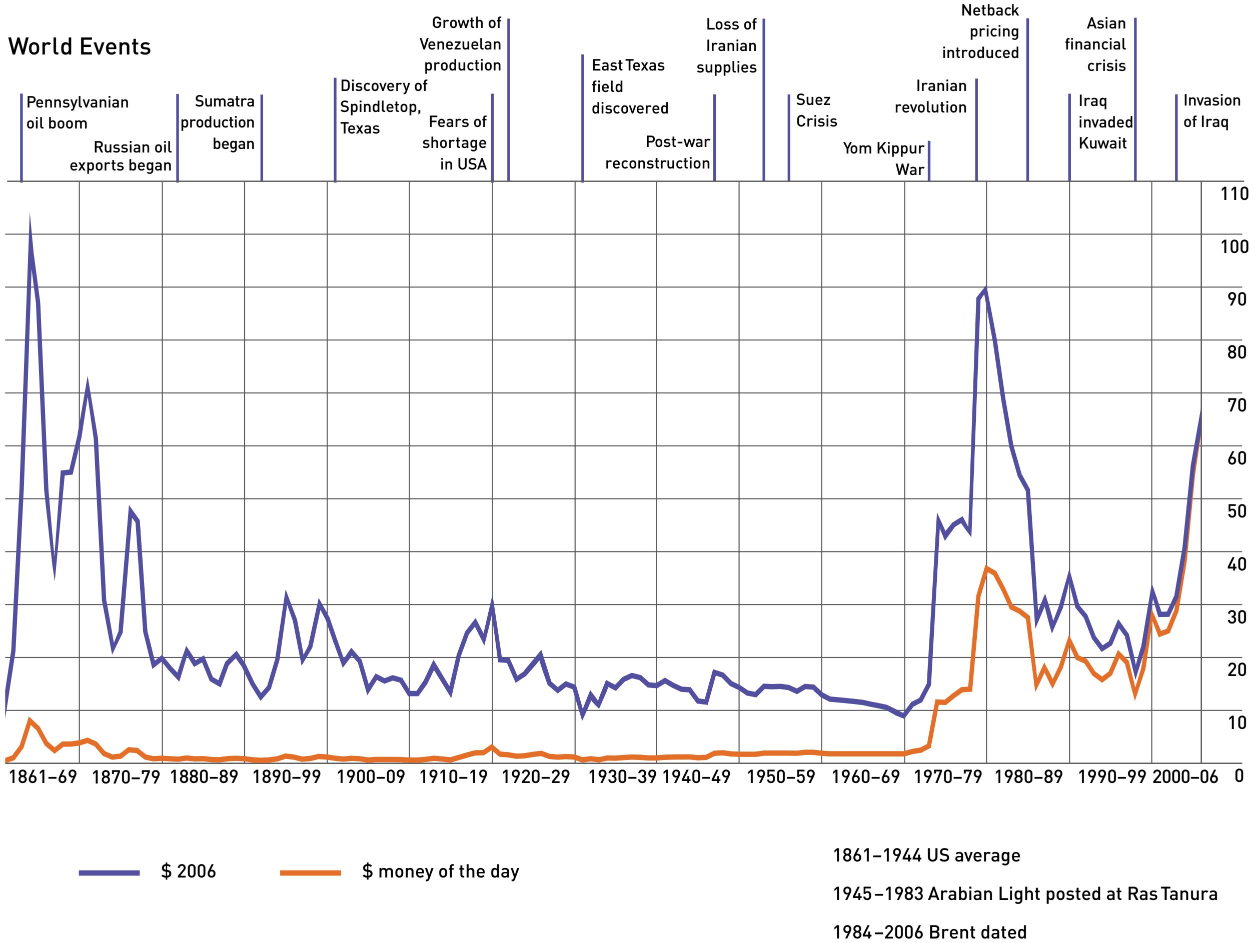
Oil also played a dominant role in the Second World War.

- Armies in North Africa, Europe, and the Soviet Union were crippled when their oil supplies were interrupted.
- Lack of oil helped end the dominance of the Japanese navy in the Pacific.
- Fuel shortages weakened German forces near the conclusion of the war.
- The first large petrochemical plants were built during the war to produce synthetic rubber.

Petroleum and petroleum products have been regarded as “strategic commodities” ever since. The industry became closely intertwined with geopolitical events, a phenomenon that continues today.

Crude oil and crude oil products are widely traded commodities, with more than half of world consumption occurring outside producing regions. Crude oil

Figure 4.16
Crude Oil Prices Since 1861
(US dollars per barrel)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

that is transported over long distances is usually carried in either oil pipelines or oil tankers. Extensive international trade provides the opportunity for political events to influence global markets and world oil prices. Major market disruptions over the last few decades are summarized below:

1951	Prime Minister Mossadegh nationalizes oil industry in Iran
1956	Suez Crisis
1967	Six-Day War
1973	Yom Kippur War; Arab oil embargo: oil prices rise from US$2.90 per barrel (bbl) in September to $11.65 in December
1979	Panic following Iranian Revolution sends oil from US$13/bbl to $34
1990	Iraq invades Kuwait; UN imposes embargo on Iraq; multinational force dispatched to Middle East
Present	US et al. invasion of Iraq; uncertainty in the Middle East, Iranian nuclear power issues and record crude oil prices above $90/bbl

The evolution of world oil prices over the modern oil era, including the impact of the above political events on prices, is shown in Figure 4.16.

Geopolitical events continue to create uncertainty in world oil markets today. Some of the major issues facing the industry today relate to:

- Instability in the Middle East: When can production be fully restored in Iraq? Will terrorist actions and civil unrest disrupt production from other major oil producers (e.g. Saudi Arabia)?

- Political uncertainty in several OPEC member countries outside the Middle East (e.g. Venezuela and Nigeria).
- Uncertainty about levels of oil exports from Russia.
- Uncertainty about how quickly oil discovered in the Caspian Sea region can be brought to market.
- Uncertainty about resolving Iranian nuclear power issues and political relationships between the US and Iran.

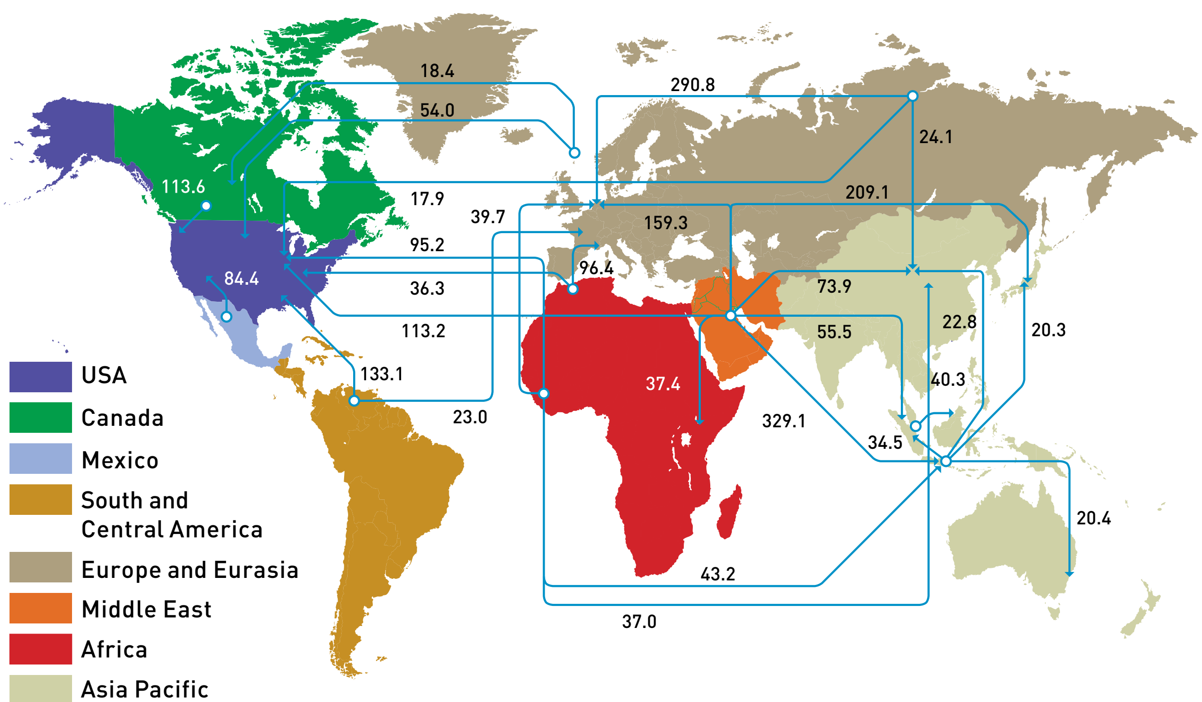
4.7 Oil and Gas Trade

Crude oil can be transported over very long distances at low cost. Oil is moved on land by pipeline and at sea by tanker. Transportation costs depend on the technology used and the distances transported, but are typically no more than US$1–$2 per barrel.

In 2006, 52.5 million barrels per day (2,590 million tonnes per year) of crude oil and products moved across international boundaries.[42] This represented almost 64 percent of world crude oil production. Trade movements in 2006 are illustrated in Figure 4.17.

Natural gas is much more difficult and expensive to transport than oil. The traditional form of transport requires the gas to be compressed to a high pressure, typically 60 to 120 times atmospheric pressure, to enable its movement to market in gas transmission pipelines. The high pressures, and the need for intermittent recompression stations, increase the cost and complexity of the gas transmission systems relative to crude oil pipelines. Since the "energy density" of natural gas in a pipeline transmission system is much lower than the energy density of crude oil in an oil pipeline, it is necessary to move a much greater volume of natural gas to transport the same amount of energy.

Figure 4.17
Major Oil Trade Movements, 2006
(tradeflows worldwide — million tonnes)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

[42] British Petroleum Company, *BP Statistical Review of World Energy 2007,* London, United Kingdom, 2007.

As a result, natural gas pipeline transmission costs, expressed as dollars per unit of energy transported, are much higher than crude oil pipeline transportation costs. For example, the cost to transport natural gas from Northeast British Columbia and Alberta Plant Gate to Chicago in July 2007 was reported to be US$0.85 per million Btus (MMBtu).[43] The cost to move Canadian light sweet crude oil from Edmonton to Chicago in July 2007 was reported to be US$1.89 per barrel,[44] or approximately US$0.32/MMBtu.

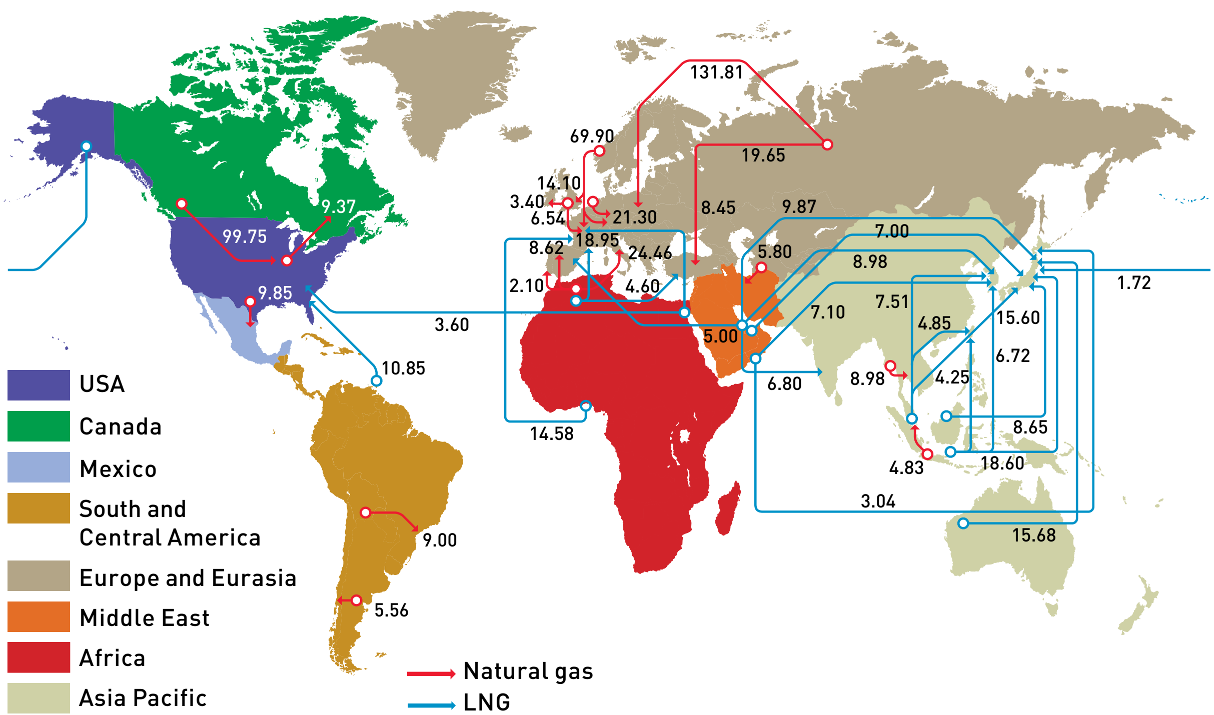
Natural gas can also be liquefied and moved by ship as LNG. The liquefaction of natural gas reduces its volume about 600-fold and allows the gas to be exported in LNG tankers. LNG production consists of a number of highly dependent operations including exploration and production of natural gas, liquefaction, transportation, regasification and storage. Natural gas can be delivered to the US as LNG within a price range of about US$2.60–$4.20/MMBtu at Henry Hub in Louisiana.[45] In spite of relatively high costs of liquefaction and transportation, the LNG business has been growing rapidly.

In 2006, 748 billion cubic metres of natural gas (dry gas and LNG) was transported across international boundaries (26 percent of total world production). Of the amount crossing international boundaries, 537 billion cubic metres was moved by gas transmission pipeline systems (72 percent of the total) and 211 billion cubic metres (gaseous equivalent) was moved by ship as LNG (28 percent of the total).

The relatively high water-borne transportation costs cause natural gas markets to be more continental in nature than the global crude oil market, as illustrated in Figure 4.18.

Figure 4.18

Major Trade Movements of Natural Gas, 2006 (tradeflows worldwide — billion cubic metres)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007, *London, United Kingdom, 2007.*

[43] Canadian Natural Gas Focus, Table A10, July 2007.

[44] Canadian Association of Petroleum Producers, *Crude Oil Report,* Calgary, Alberta, July 2007.

[45] Center for Energy Economics, *An Overview of LNG, its Properties, Organization of the LNG Industry and Safety Considerations*, updated January 2007, p. 5.

4.8 North American Energy Supply

North America is one of the world's largest energy producing and consuming regions. In 2006, North America produced 16.5 percent of the world's crude oil, 26.5 percent of the world's natural gas, 20.5 percent of the world's coal, 33.5 percent of the world's nuclear energy, and 20.1 percent of the world's hydroelectricity.[46] However, North America has limited reserves of conventional crude oil and natural gas and is not able to meet its needs without imports. In 2006, North American crude oil production was 13.7 million barrels per day, only 55 percent of total consumption. The remainder was imported, with much coming from politically unstable regions. In the same year, North American gas production provided 98 percent of the continent's needs and the remainder was imported. Continental gas supply appears to be peaking, and increased LNG imports are expected. In 2006, the US and Mexico imported 17.5 billion cubic metres of liquefied natural gas from other countries, mainly Trinidad and Tobago.

North America has substantial coal reserves, an established nuclear industry, and limited potential for further hydroelectricity development near heavily populated areas.

[46] British Petroleum Company, *BP Statistical Review of World Energy 2007,* London, United Kingdom, 2007.

North America's oil and gas reserves do not represent a significant percentage of total global reserves, whereas its coal reserves (mostly in the US) comprise about a quarter of the world's total. Mexico nationalized its oil sector in 1938, creating Petróleos Mexicanos (PEMEX). Since that time, PEMEX, as a state-owned company and symbol of national sovereignty, has held exclusive rights over oil and gas exploration and production in the country. The exploitation of Mexico's oil and gas reserves is constrained by Mexico's constitution.

However, North America also has substantial non-conventional oil and gas reserves. Its commercialized non-conventional oil is found primarily in the oil sands in Canada's province of Alberta, one of the world's largest hydrocarbon deposits.[47] Non-conventional natural gas resources are available in the upstream US Rocky Mountains region, western Canadian coal seams, and gas hydrate deposits found in almost all offshore areas and in northern permafrost regions.

CERI recently completed a comprehensive study of Alberta's oil sands industry.[48] This study examined the

[47] Other non-conventional oil sources such as oil shale deposits in the United States and other countries offer the prospect of commercialization.

[48] Canadian Energy Research Institute, *Cogeneration Opportunities and Energy Requirements for Canadian Oil Sands Projects — Parts I to IV:* Study No. 112, Calgary, Alberta.

supply costs and future production of bitumen and synthetic crude oil with respect to their input requirements. The major inputs needed to produce oil sands (crude bitumen and synthetic oil) are electricity, natural gas, diluents, condensate, and labour. As development of Alberta's resources continues at a rapid rate, the scarcity of the input requirements may either restrain the production and/or increase the costs of production. In this study, the availability of inputs and the impact of new extraction technologies have been examined as well. Furthermore, the study investigated cogeneration technology for generating the heat and electricity used for extraction and processing of crude bitumen. Given different levels of cogeneration development, CERI conducted sensitivity analyses to evaluate the potential electricity exports from the oil sands region.

CERI considered two scenarios, unconstrained and constrained, for oil sands production. In the unconstrained scenario, all announced projects proceed as planned while in the constrained scenario, mainly due to infrastructure constraints, reasonable delays are applied to project schedules. The study concludes that Alberta's oil sands industry has a very robust future.

- Alberta's oil sands are among the world's largest hydrocarbon deposits, with remaining established reserves of 173 billion barrels of crude bitumen[49] at the end of 2006. In the same year, the conventional crude oil reserve of Canada was 6.9 billion barrels. In 2002, Alberta's oil sands became formally recognized as forming a significant part of global oil reserves,[50] placing Canada (179.6 billion barrels) second only to Saudi Arabia (262 billion barrels) in total oil reserves.

- While oil sands production costs are higher than those of conventional oil, increasing oil prices, very low finding costs and continuing technological advances have allowed the production from Alberta's oil sands to become commercially viable and to compete in the international oil market.
- Canada's oil sands industry produced slightly more than one million barrels per day of synthetic crude oil and unprocessed crude bitumen in 2005, representing approximately 39.4 percent of total Canadian oil production.
- CERI has projected that bitumen production under the unconstrained scenario will rise from 1.18 million barrels per day (MMbpd) in 2005 to 4.7 MMbpd in 2020. During the same period, synthetic crude oil production will rise from 0.64 MMbpd to 2.47 MMbpd. Under the constrained scenario, the bitumen production will increase to 3.6 MMbpd and synthetic crude oil to 1.9 MMbpd in 2020.
- CERI's analysis[51] indicates that the oil sands industry requires West Texas Intermediate (WTI) oil prices of above US$52 per barrel at Cushing, Oklahoma, to earn an adequate return on investment.
- The industry is facing challenges related to environmental impact capital costs; a variety of labour availability and productivity issues; energy requirements, sources and costs; water requirements and supply; diluent requirements and supply; infrastructure constraints; market constraints; and concurrent production of natural gas and crude bitumen. Resolution of these issues requires ongoing industry attention and ingenuity.

The US and Canada[52] also have substantial potential non-conventional gas resources in the form of coal bed methane (CBM), gas from tight sands, deep offshore gas, and gas hydrates. CBM refers to production of methane found in coal deposits.

- The AEUB[53] estimates the Alberta initial established reserves of CBM to be 27.8 billion cubic metres, of which 24.7 billion remained at the end of 2006.

49 Alberta Energy and Utilities Board (AEUB), *Alberta's Energy Reserves 2006 and Supply/Demand Outlook 2007-2016*, ST98-2007.

50 The *Oil & Gas Journal* recognized these as reserves at year-end 2002.

51 Canadian Energy Research Institute, *Oil Sands Industry Update, Production Outlook and Supply Cost, 2007-2027.*

52 Alberta, British Columbia, and Nova Scotia.

53 AEUB, *Alberta's Energy Reserves 2006 and Supply/ Demand Outlook 2007-2016*, ST98-2007, Ch. 4.

- Commercial production of coal bed methane in Alberta began in 2002. In 2006, production of CBM amounted to 4.7 billion cubic metres, with the prospect of significant growth over the coming decade.
- Gas hydrates, formed under conditions of high pressure and low temperature, are found off all three of Canada's coasts and beneath permafrost, particularly in the vicinity of the Mackenzie Delta. Large deposits of gas hydrates are also found off the coasts of several energy-importing nations including the United States, Japan, China and India. In general, offshore gas hydrates lie under at least 300 metres of water that is close to zero degrees Celsius. Natural Resources Canada[54] states, "The worldwide amount of methane in gas hydrates is considered to contain at least 1 x 104 gigatons of carbon in a very conservative estimate. This is about twice the amount of carbon held in all fossil fuels on earth." Even so, no estimates are yet available about what percentage of the methane in place could be considered recoverable, although experimental work in the Mackenzie Delta and Alaska has produced encouraging results. The United States Geological Survey (USGS) estimates the world-wide amount of methane in place within gas hydrates to be 400 million trillion cubic feet (tcf). Assuming a recovery factor of, say, 1 percent, the recoverable gas hydrate resource of 4 million tcf is almost 300 times as large as the USGS's estimate of the world's remaining recoverable conventional natural gas[55] (the latter consisting of 8,452 tcf of gas from existing discoveries plus 5,196 tcf not yet discovered).

There are many challenges related to unconventional gas production including high capital costs, land access issues, and water disposal and other environmental issues.

Renewable energy includes solar, wind, biomass, hydro, geothermal and ocean energy. In terms of renewables in North America, Canada and Mexico both have available sites for new large-scale hydroelectric plants, whereas the best sites in the US have already been developed or have been inhibited by the NIMBY (not-in-my-back-yard) factor. All three countries have untapped technical potential for wind, biomass and geothermal.

Renewable energy includes solar, wind, biomass, hydro, geothermal and ocean energy.

In Mexico, more than 72 percent of renewable supply comes from hydroelectric, followed by almost 20 percent geothermal. In fact, Mexico is the third largest producer of geothermal electricity in the world, after the United States and the Philippines. To date, wind power does not contribute greatly to the generation mix. Currently, two wind power facilities, with combined capacity of 3 megawatts (MW) operate in Mexico. In 2005, the state-owned Comisión Federal de Electricidad (CFE) which controls about two-thirds of the installed generating capacity of Mexico has planned to increase the wind power capacity by 80 MW.[56]

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54 Accessed at http://ess.nrcan.gc.ca/2002_2006/ghff/index_e.php

55 USGS estimate of 400 million tcf of gas hydrates cited in *Gas Daily*, August 20, 2007, p. 10; USGS conventional gas resource estimate accessed at http://pubs.usgs.gov/dds/dds-060/ESpt4.html

56 www.eia.doe.gov/emeu/cabs/mexico.html

Canada ranks second to China in the generation of hydro power. Hydroelectric accounts for 97 percent of Canada's generation from renewable and 58.3 percent of its total generation mix. The share of wind power in the generation mix is about 0.2 percent. Wind energy is expected to grow substantially, partly as a result of the federal government's Wind Power Production Incentive program.[57]

In the United States, the shares of hydroelectric power and biomass from renewables in the national generation mix are about 74 percent and 12 percent respectively. The remaining 14 percent are mainly wind, geothermal, and waste. The Energy Information Administration[58] forecasts 16 MW of capacity additions for hydro and 6,412 MW for non-hydro renewables by 2010. The generation capacity of hydro in the US was 77,354 MW compared to 25,553 MW of non-hydro renewables in 2005.

4.9 Energy Supply: A Summary Comment

The world's resources of hydrocarbon-based sources of energy are adequate to meet demand through the year 2050 (and for coal much longer). Crude oil will maintain its dominance in transportation but slowly give way to natural gas in other uses because of the lower emissions from natural gas. Coal, with high emissions but low relative price, will retain its market share and then grow after environmental issues have been resolved. The problems associated with fossil fuels are not immediately problems of adequacy; rather, they are problems of location. The resources are not located where they are needed. Therefore, issues of transportation and security will take on added importance in the early part of this century.

While large-scale intercontinental movements of oil are well established, natural gas will inevitably become a globally traded commodity as well, giving rise to a large fleet of tankers and port facilities to handle them. In the early years of the 21st century, the problems of siting such facilities may become a significant hindrance to the efficient evolution of the LNG trade.

The increasing importance of environmental considerations in relation to the likely or most desirable mix of energy sources is gradually being recognized.

Hydroelectricity and nuclear power — with similar environmental advantages and some adverse perceptions based on costs, safety, and other environmental impacts — will see a resurgence of interest as understanding of them grows and the environmental considerations become more urgent. Renewable sources of energy, such as solar and geothermal, will take hold gradually, barring a significant technological breakthrough, because the existing stock of capital dedicated to providing and using energy is like a huge ship on a calm sea — it takes time and effort to turn it around.

The increasing importance of environmental considerations in relation to the likely or most desirable mix of energy sources is gradually being recognized. This suggests the importance of pursuing appropriate technological innovation so that we use our existing supplies effectively and find new sources of energy that meet the needs of both humanity and the environment. This subject is addressed in the following chapter.

[57] Natural Resources Canada, accessed at www2.nrcan.gc.ca/es/erb/erb/english/View.asp?x=68

[58] www.eia.doe.gov/cneaf/electricity/epa/epat2p4.html

5 ENERGY and the Environment

5.1 Energy Supply Revisited

In Chapter 2 we discussed various dimensions of energy systems, most notably the technological and environmental dimensions. The idea of resource-use sustainability has two aspects: one is the abundance of various sources of energy; the other relates to the effect of their use on the environment. Chapter 3 provides a historical overview of energy consumption and Chapter 4 reviews the longevity of various non-renewable sources of energy, such as oil, gas, and coal. In this chapter, we build on those results, to address sustainability in greater depth and to consider alternatives to fossil fuels in greater detail. We begin with the global implications of climate change that may be attributable, at least in part, to the ongoing use of energy. Then we turn to the various sources of energy, both non-renewable and renewable, to sketch their relevance to both aspects of sustainability.

5.2 Sustainable Energy and Economy

As noted in earlier chapters, economic activity leads to unwanted waste products that must be managed. While one aspect of sustainability relates to whether or not there are limits on the fuel sources of the future, another applies to whether or not the biosphere is capable of absorbing the related waste products — solid, liquid, and gaseous. Energy use generates waste products that can affect humans directly, through health, and indirectly, by affecting the environment at local, regional, and global levels. This section looks at both the sustainability of fuel sources and the implications for energy systems of the need to manage their emissions.

The emissions that must be managed encompass toxic substances (sulphur compounds, nitrogen and mercury), greenhouse gases, and particulates. These emissions can directly affect human health and can also affect the environment around us, thus affecting humans indirectly. The direct effects on human health from what are sometimes called critical air contaminants have been recognized and, in some regions, addressed through changes in use or technology to reduce the harmful emissions.[59] While it is important to understand and continue to address this aspect of the problem, it is beyond our scope here. We focus here on the global impact of greenhouse gases, and what that means for evolving energy systems.

The essence of global warming is that certain gases in the Earth's atmosphere result in a thermal blanketing effect that keeps the temperature higher than it would be in their absence.

Greenhouse gases (GHGs), in order of importance, include water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), followed by a host of other gases that contribute to the greenhouse effect. Although human activities do not directly affect the volume of water vapour in the atmosphere, the more

[59] California, for example, has introduced stringent regulations to limit harmful emissions. A technological example is catalytic converters in automobiles that reduce emissions of carbon monoxide, volatile organic compounds, and nitrous oxide.

global warming there is because of human activity, the greater evaporation there will be. Thus there is a cycle related to human activity that contributes to ever-increasing concentrations of GHGs. The main human contributor to this cycle is through combustion and related emissions of carbon dioxide (CO_2).

The essence of global warming is that certain gases in the Earth's atmosphere result in a thermal blanketing effect that keeps the temperature higher than it would be in their absence. Without this effect, life as we know it may not have evolved. The natural mean global temperature of the Earth is about 15 degrees Celsius. Without this atmospheric warming effect, the mean temperature would be approximately minus 18 degrees Celsius, well below freezing.

In 1958, the concern that increased concentrations of CO_2 caused by human activity might eventually alter the global climate to our detriment spurred scientists to begin long-term measurements of these concentrations. One investigator, Charles Keeling, began measuring at a remote station in Hawaii. Mauna Loa Observatory (MLO)[60] is located on an island in the middle of the Pacific Ocean, away from major air pollution sources. MLO is an ideal place to sample the atmosphere. MLO also protrudes through the strong marine temperature inversion layer present in the region. This inversion layer acts like a lid and keeps the lower local pollutants below the observatory.

To look further back in time, as far back as the mid-1800s, other scientists have analyzed data from the study of ice cores. An ice core[61] is a sample from the accumulation over many years of snow and ice that has re-crystallized and trapped air bubbles from previous time periods. The composition of these ice cores, especially the presence of hydrogen and oxygen isotopes, provides a picture of the climate at specific times in the past. Figure 5.1 shows the gradually

60 www.mlo.noaa.gov/lowhome.htm

61 http://en.wikipedia.org/wiki/Ice_core

increasing concentrations that have been estimated through these measurements.

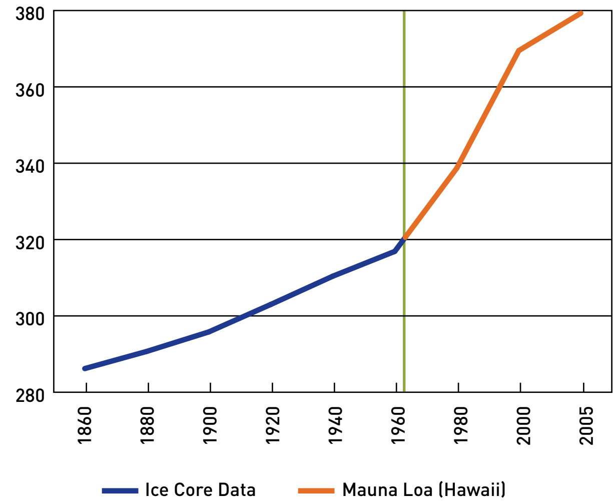
The diagram is a combination of direct measurements taken at a variety of remote locations (including the remote station on Mauna Loa Volcano) and indirect measurement of trapped bubbles of air in ice cores from polar ice sheets. The cores are taken from layers that connect them to earlier periods. The results of the core analysis lead many scientists to believe that the atmospheric concentration of carbon dioxide (CO_2) increased by roughly 11 percent over the 100 years between 1860 and 1960. The direct measurements between 1960 and 2005 suggest the growth in concentration over that 45-year period was close to 20 percent, implying an acceleration in the growth of CO_2 concentration. The combined increase over the past 145 years is some 32.5 percent, and other work connects this closely with the increase in the use of fossil fuels.[62]

The carbon added to the atmosphere is also removed, in part, through various sinks: oceans, forests, and soils. However, it takes a relatively long time, approximately 100 years, for the full cycle to be completed. Unfortunately, other GHGs, such as methane and nitrous oxide, have also increased significantly. These latter gases have a much greater warming effect than carbon dioxide, and as a result, have increased the potential warming effect by 75 percent over CO_2 alone. However, about half of this potential increase has been neutralized by the net cooling effect of increased particulate matter. Because the reduction of particulate emissions is an objective of regulations in many countries, they are likely to grow more slowly in the future and, in a slightly perverse result, make a smaller contribution to offsetting the warming effect of other emissions.

There is ongoing discussion on the impact of the growing concentrations of carbon, with some disagreement as to the causes and the likely consequences, in part because the normal cycles of climate involve very long periods of time. Yet there is growing evidence that some effects are being observed. And while debate has centred on the ultimate effect of a doubling of carbon

Figure 5.1

Atmospheric Concentrations of Carbon Dioxide, 1860–2005 (parts per million)



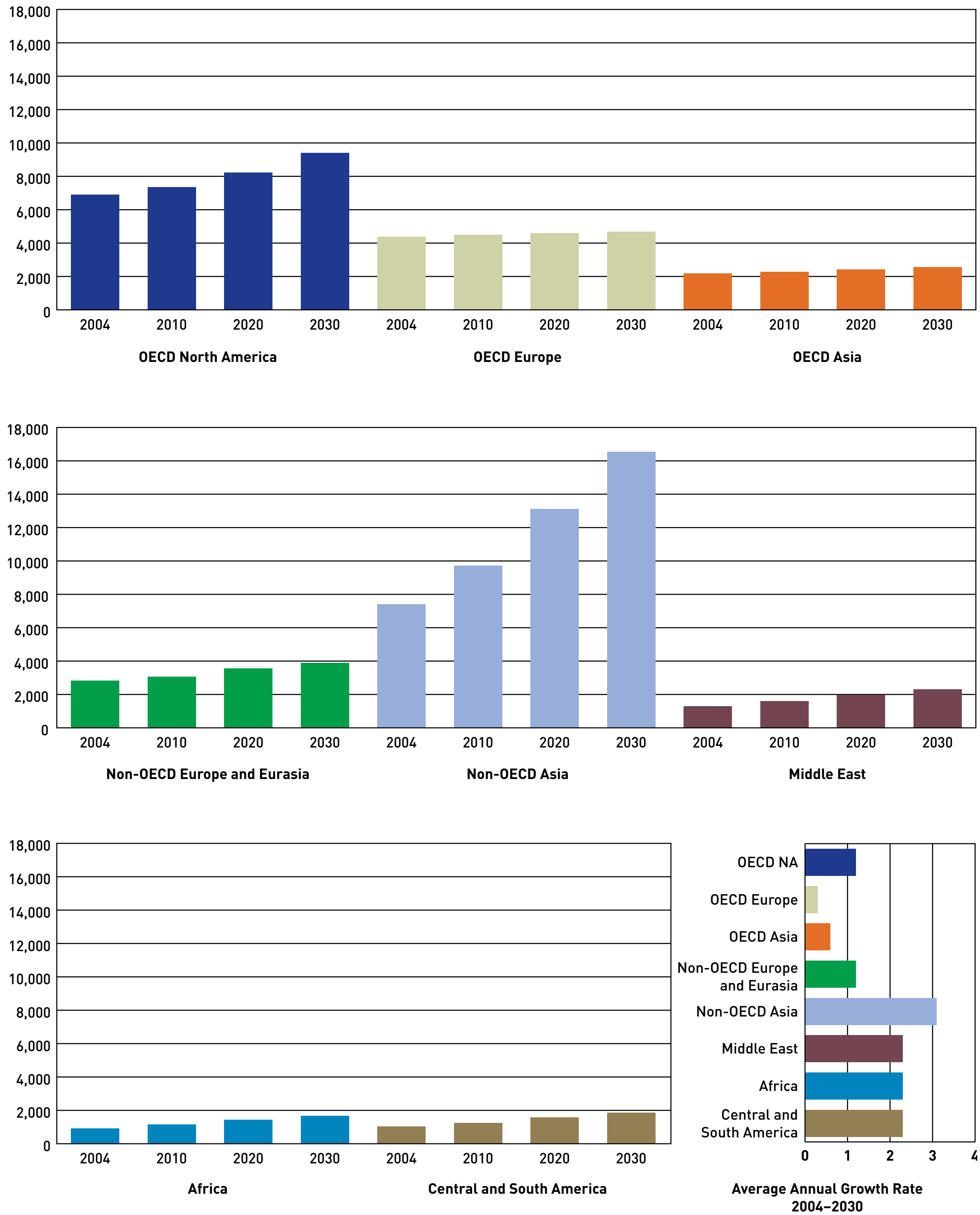
SOURCE: www.johnstonsarchive.net/environment/co2table.html

concentrations, projected to increase global mean temperatures by roughly 2.5 degrees Celsius, the possibility of even higher concentrations suggests that action is urgent. A doubling of carbon dioxide (CO_2) with a consequent temperature increase of 2.5 degrees, on average, masks significant variations that would have severe adverse effects in some regions from changing circulation, precipitation, volatility, soil moisture, ocean currents, and more. All of these things would fundamentally alter the ecology of regions, with largely unpredictable results. Some regions might benefit, but many would be severely disadvantaged. A quadrupling of carbon would lead to *average* temperatures some 8–10 degrees higher, with highly unpredictable but likely universally adverse effects on both ecology and the economy, notably the flooding of coastal areas as glaciers melt.

Figure 5.2 sets out the total carbon emissions by region for the year 2004 (actual) and the EIA's projection of CO_2 emissions until 2030. The average annual growth rate of CO_2 for each region is also forecasted. Over the period 2004 to 2030, non-OECD Asia shows the highest growth rate (3.1 percent) while OECD Europe displays the lowest growth rate (0.3 percent).

[62] The main cause of increasing concentrations of CO_2 prior to 1860 is believed to have been deforestation.

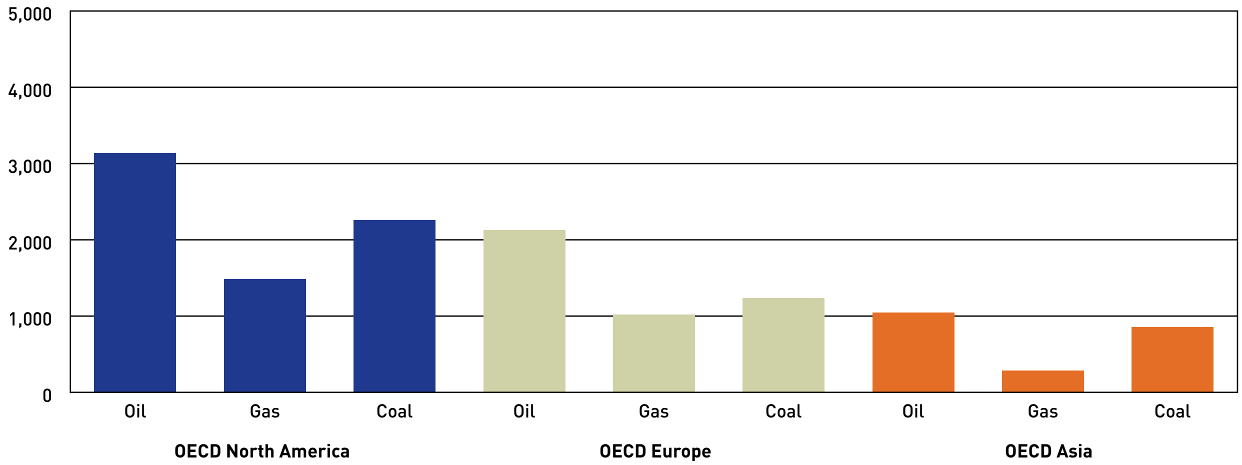
Figure 5.2
Total CO_2 Emissions by Regions, 2004–2030 (million tonnes)

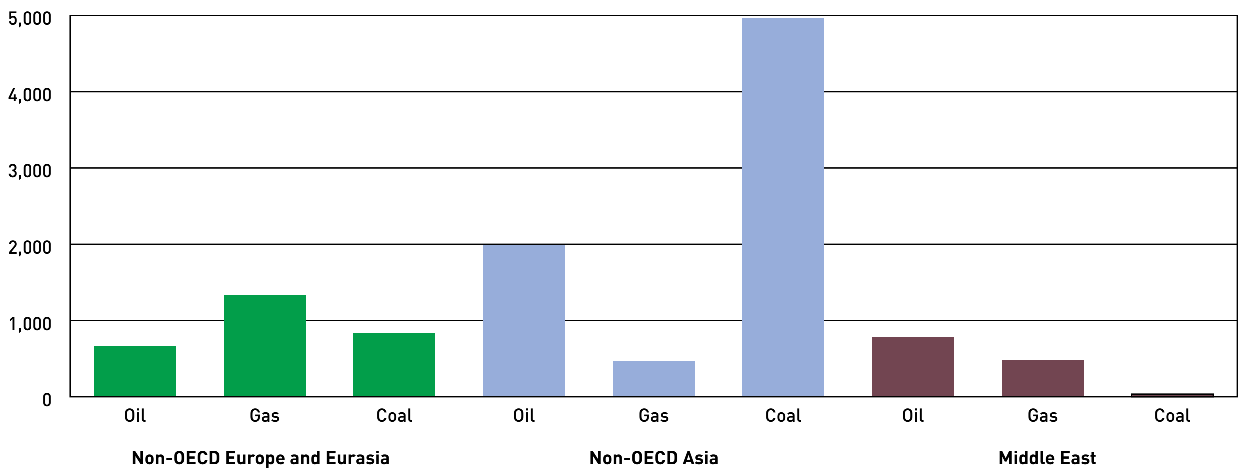


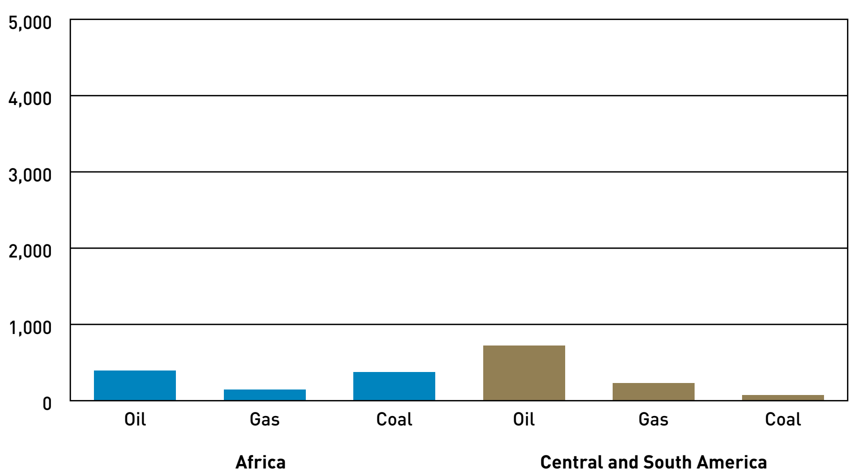
SOURCE: Energy Information Administration, International Energy Outlook 2007, *Table 11, p. 74, accessed at www.eia.doe.gov/oiaf/ieo/ieorefcase.html*

Figure 5.3

CO_2 Emissions by Fuel in 2004 (million tonnes)







World CO_2 Emissions (Mt)

	Total	Share
Oil	10,852	40.3%
Gas	5,441	20.2%
Coal	10,617	39.5%
	26,910	100%

SOURCE: Energy Information Administration, International Energy Outlook 2007, *Tables 11 to 13, accessed at www.eia.doe.gov/oiaf/ieo/ieorefcase.html*

Figure 5.3 shows CO_2 emissions, by fuel, in different regions. In 2004, coal emissions are highest in non-OECD Asia followed by OECD North America. Worldwide, coal and oil contribute roughly 40 percent each of total CO_2 emissions, whereas natural gas accounts for only 20 percent.

It is evident from these projections that the developing world is expected to increase total emissions much more rapidly than developed countries.

The issue of global warming and the inexorable increase in emissions that is likely over the next century have led to questions such as whether or not the world's ecology will continue to be sustainable. Such questions have led to the international response to climate change which was launched in 1992 at the Earth Summit in Rio de Janeiro and then further codified in the 1997 Kyoto Protocol. In 2002, countries set binding targets to reduce emissions 5.2 to 6 percent below 1990 levels by 2012.

The United States initially signed but ultimately did not ratify the Kyoto Protocol. However, in February 2002, the United States introduced the Clean Skies and Global Climate Change initiatives,[63] in which targets for reduction in GHGs are linked directly to the US GDP. The greenhouse gas intensity of the US economy is set to decline by 18 percent in the next 10 years under these targets.

Although Canada ratified the protocol in 2002, the government in 2006 stated that the targets are unachievable and set targets for the Canadian environment and development of clean technology.

Another aspect of sustainability that requires some consideration relates to whether or not energy supplies will be adequate to meet demand in the far future. This we turn to now. Can we take comfort that there will be adequate future supplies of energy? We address this in a somewhat abbreviated way by looking at individual sources of energy and their outlook.

63 Accessed at www.whitehouse.gov/news/releases/2002/02/climatechange.html

5.3 Energy Sources: Availability and Impact

5.3.1 Fossil Fuels

The history and prospects for fossil fuels have been explored extensively in Chapters 3 and 4 and will only be summarized here. Our previous discussion implies that natural gas and oil will last well into this century, beyond 2050, and coal could last for hundreds of years at currently projected rates of consumption. Thus, fossil fuel sources exist for at least another generation, but after that the picture is less clear.[64] There are a number of renewable resources that may be able to fill any gaps after 2050, and these are discussed below.

However, the increasing global awareness of the implications of greenhouse gas (GHG) emissions raises the possibility of a limit on their use not connected with their physical availability but rather to their overall effect on the environment. We must, therefore, also consider the effect alternative fuels have on the environment in assessing their suitability to play a role in replacing fossil fuels.

64 There is a theory, which is coming back into vogue, to the effect that oil and gas are actually renewable resources. Again, the issue is beyond our scope. For a brief review and discussion, see Peter R. Odell, *Why Carbon Fuels Will Dominate the 21st Century's Global Energy Economy,* Multi-Science Publishing Co., United Kingdom, 2004, Chapter 6.

5.3.2 Hydro Power (Large and Small)

The best known and most widely used of the renewable energy sources is hydro power. In 2004, the world-installed hydro generation capacity[65] was 851,000 megawatts (MW), representing over 21 percent of the world's total electricity generation capacity. In the same year, electricity generation from hydro was 2,809 terawatt-hours per year (TWh/yr) representing 16 percent of total electricity generation (17,408 TWh).

The largest hydro power producers[66] around the world are China (13.7 percent), Canada (11.5 percent), Brazil (11.5 percent), the US (9.6 percent) and Russia (5.8 percent). More than half of the world's small hydro power (from 10 to 30 MW) capacity is in China.[67]

The theoretical potential for hydro power, based on the world's annual water balance, is just over 40,000 TWh/yr. When admittedly rough technical criteria are applied, the theoretical potential declines to just over 14,000 TWh/yr. And finally, the application of equally approximate economic criteria results in a potential of some 8,000 TWh/yr, or just over two and half times the 2004 supply.[68]

There are advantages and disadvantages to hydro power. Hydro power does involve some emissions because of the decay of plant matter at the bottom of reservoirs and the removal of gases from just above the water surface.[69] However, these emissions are an order of magnitude or two less than those from fossil fuels.[70] There are local and downstream impacts, however, that have led to significant resistance in many areas. Most significantly, the very high capital costs make hydro difficult to consider in many developing countries, where the unrealized potential is highest.

[65] International Energy Agency, *World Energy Outlook 2006*, p. 493.

[66] British Petroleum Company, *BP Statistical Review of World Energy 2007,* London, United Kingdom, 2007.

[67] International Energy Agency, *Energy Technology Perspectives 2006*, p. 206.

[68] www.uniseo.org/hydropower.html

[69] A. Tremblay & others, *The Issue of Greenhouse Gases from Hydroelectric Reservoirs: From Boreal to Tropical Regions*.

[70] There are also significant emissions associated with the cement used in constructing dams. However, this is being minimized through the use of roller compacted concrete technology, which results in much less cement being used.

On the other side, the low emissions are attractive and the renewable nature of the flows that fuel hydro power means it is essentially inexhaustible and also has a low lifetime cost. As well, hydro power has many technical advantages with respect to the services it can supply to the electricity system, including cold start capability, voltage control, and spinning reserves. Large hydro costs of 3.4 to 11.7 cents a kilowatt-hour are among the lowest of all the various means of power generation, and small hydro costs are not much more then 5.6 cents.[71] That helps to explain why hydro plants supply about 21 percent of the world's electricity.

5.3.3 Nuclear Power

In 2006, 441 nuclear power reactors were in service around the world with a combined generation capacity of 369,122 megawatts (MW). In the same year, an additional 27 new reactors were under construction with a combined capacity of 21,421 MW.[72]

Approximately 55 percent of total nuclear power capacity is in the United States (26.6 percent), France (17.2 percent), and Japan (12.9 percent).

Canada's total capacity of 12,599 MW ranks 8th in the world, and its nuclear industry is highly regulated. The *Nuclear Safety and Control Act*[73] governs the use of nuclear energy, materials, and equipment in Canada. Furthermore, on May 31, 2000, the Canadian Nuclear Safety Commission (CNSC)[74] replaced the Atomic Energy Control Board (AECB) which had been created in 1946 under the *Atomic Energy Control Act*. The CNSC regulates the Canadian nuclear industry to protect the safety, security and health of Canadians and the environment from nuclear radiation and waste. The CNSC regulations apply to all nuclear activities including uranium mines, refineries, conversion facilities, nuclear power stations, and radioactive waste resulting from nuclear facilities. The CNSC regulations also apply to hospitals and clinics that use radioisotopes in diagnosis or cancer treatment.

[71] International Energy Agency, *World Energy Outlook 2006*, p. 232.

[72] Y. Sokolov & A.Macdonald, *Nuclear Power — Global Status and Trends*.

[73] http://laws.justice.gc.ca/en/N-28.3/

[74] http://nwt-tno.inac-ainc.gc.ca/mpf/authorit/cnucsafc_e.htm

The supply of fuel that can be used in generation of nuclear power is produced either directly from the uranium mines or supplied from secondary sources. The secondary sources include civil stockpiles, re-enriched depleted uranium tails, recycled uranium and plutonium from spent fuel uranium used for military weapons, and unconventional sources such as uranium from phosphate deposits, black shale deposits, and granite rock. Seawater is another vast source that has a low concentration but amounts to potentially some 4.5 billion tonnes.

In 2005, approximately 108 million pounds (49,000 tonnes) of uranium (U_3O_8)[75] was produced around the world, and the three largest producers were Canada (28 percent), Australia (23 percent), and Kazakhstan (10 percent). The World Nuclear Association[76] estimates that in 2007, approximately 66,500 tones of uranium will be used for nuclear power generation.[77]

In the last three years, the price of uranium[78] has increased from US$29 per pound (US$63/kg) in May 2005 to US$43/lb (US$94/kg) in May 2006 and to US$133/lb (US$292/kg) in May 2007.

75 www.uranium.info/publications/NRSample.pdf

76 www.world-nuclear.org/info/reactors.htm

77 This can be translated to 78,500 tonnes of uranium oxide from mines (yellow cake).

78 www.uranium.info/prices/monthly.html

5.3.4 Nuclear Fission

Nuclear fission,[79] harnessed to produce electricity, began to increase significantly after 1973, when oil prices started their steep upward climb. In some countries, such as France, it became the dominant source of electricity production, accounting for over 75 percent of production. Nuclear power accounts for approximately 16 percent of the world's electricity generation (17,408 terawatt-hours (TWh)) and 6.4 percent of the world primary energy supply (11,204 million tonnes of oil equivalent (Mtoe)). In 2006, approximately 2,619 TWh of electricity was generated from nuclear power, mainly in industrialized countries.

Until recently, some forecasters were predicting that nuclear power would not grow in importance and might even decline over the next several decades. Their reasons included low energy prices from other sources (prevailing until recently), the high costs of nuclear capacity, and public perceptions about the dangers associated with nuclear facilities.[80] Today, however, energy prices are higher, the lifetime costs of nuclear facilities are competitive with other forms of energy generation, and the comparative risks are increasingly understood if not yet fully accepted by the public. The outlook for nuclear power is becoming much more

79 Splitting of the nucleus of an atom into parts which can release large amounts of energy.

80 See Section 4.3 for a brief discussion.

Table 5.1
Emissions Avoided from the Use of Nuclear Energy in Canada, 1990–2004

Sources	GHG Emissions from Electricity Generation kt CO_2 eq			
	1990	1995	2000	2004
Coal	78,800	83,100	104,800	96,000
RPP	11,400	6,990	8,800	12,300
Natural Gas	4,050	9,150	16,100	15,500
Nuclear	–	–	–	–
Hydro	–	–	–	–
Biomass	–	–	–	–
Others	404	522	1.260	4.340
Total	**94,600**	**99,700**	**131,000**	**128,000**

	Avoided GHG Emissions kt CO_2 eq			
	1990	1995	2000	2004
Coal	70,824	94,152	65,240	86,092
or RPP	54,459	68,768	48,759	54,554
or Gas	30,874	42,738	34,886	44,581

SOURCES: Environment Canada, National Inventory — Annex 9, and CERI, Estimated Avoided GHG.

positive. Moreover, the potential contribution from nuclear power in limiting greenhouse gases (GHGs) is increasingly credited in assessments of alternatives.

The use of nuclear energy for generating electricity is one way of moderating the emissions of GHGs and acid rain associated with the burning of fossil fuels. Table 5.1 shows the GHG emissions resulting from Canadian electricity generation for the period 1990 to 2004. The same table illustrates the avoided GHGs consequent to the use of nuclear energy rather than coal, refined petroleum products (RPP), or natural gas.

The nuclear story does have a negative side. Concerns exist over the use of spent nuclear fuel from reactors. Nuclear waste is radioactive, with some elements remaining hazardous thousands of years into the future.

These safety and environmental concerns contribute to a negative public perception of nuclear energy in some countries.[81] As well, the high capital costs of nuclear energy and some experiences over the past decade with cost overruns associated with refurbishment of nuclear facilities have contributed to the negative perception of some members of the public. While cost overruns have been caused by numerous factors, including some related to the decision-making of governments; and although more recent examples of on time and on budget new construction are available, some negative perceptions remain. Therefore, in spite of a widespread recognition that nuclear energy is a low emitter of GHGs, concerns related to waste management, safety, and efficiency continue to challenge the industry and affect the potential for new nuclear plants. In 2005, the International Atomic Energy Agency (IAEA)[82] sponsored a global nuclear survey (18 countries). The survey found that "while majorities of citizens generally support use of existing nuclear reactors, most people do not favour the building of new plants". It is likely that, as the public's understanding of nuclear power increases, its advantages will be seen to outweigh its disadvantages and it may become more widely accepted as a legitimate option in resolving energy supply issues.

[81] Interestingly, an OECD report on the public perception of nuclear energy shows that perception is irrelevant to the nuclear policy of the country (OECD, undated, p. 109).

[82] Global Public Opinion on Nuclear Issues and the IAEA, accessed at www.iaea.org/Publications/Reports/gponi_report2005.pdf; p. 6.

In Canada, spent fuel is now safely stored where the waste is produced at seven licensed sites.[83] After its removal from a reactor, spent fuel is first placed in wet storage for seven to 10 years to reduce its heat and radioactivity. It is then transferred to dry storage. The design life of existing dry storage containers is 50 years, although the expected life is thought to be 100 years or longer.

Although the storage options are expected to perform well over the near term, existing reactor sites were not chosen for their technical suitability as permanent storage sites. In 2002 the Government of Canada passed the *Nuclear Fuel Waste Act* for this purpose, and established a Nuclear Waste Management Organization (NWMO).[84] The Act required the NWMO to study the wastes produced by Canada's electricity generators and their site selection and storage techniques. The objective of the NWMO study was to investigate and recommend the best alternative options to the federal government for the long-term management of used nuclear fuel.

The NWMO engaged interested Canadians, stakeholders and specialists in its three year study and reviewed the benefits, risks, and cost of three technical methods: (1) deep geological disposal in the Canadian Shield; (2) storage at nuclear reactor sites; and (3) centralized storage, either above or below ground.

In November 2005, the NWMO released its final study on "The Future Management of Canada's Used Nuclear Fuel"[85] and recommended the adaptive Phased Management approach for the long term care of Canada's used nuclear fuel. The approach offers to maintain used nuclear fuel at the reactor sites, while preparing for centralization at a site in a deep repository — with the option of an interim shallow, underground storage facility at the site.

Furthermore, the report proposed that the process of implementation of centralized facilities should be in the provinces that have benefited from activity associated with the nuclear fuel cycle.[86] This includes the three provinces that generate electricity from nuclear power (Ontario, New Brunswick and Quebec), as well as Saskatchewan, which has benefited economically from mining the uranium that is used to make nuclear fuel.

5.3.5 Other Nuclear Options

While the available resources of uranium are adequate through 2050, a very high nuclear growth scenario could envisage supply problems after 75 to 100 years. This means that a technological response might be necessary to offset the declining availability of conventional uranium resources. One answer would be the exploitation of seawater, as noted above. Other approaches include variants on what are called fast breeder reactors, which allow the extraction of up to 100 times the amount of energy from uranium than is possible using light water reactors. Thermonuclear

83 Four sites are located in the province of Ontario (Bruce, Pickering, Darlington Nuclear Power Stations and Chalk River Laboratories). One site is located in each of the provinces of Quebec (Gentilly Nuclear Power Station), New Brunswick (Point Lepreau Nuclear Power Station), and Manitoba (Whiteshell Laboratories).

84 www.nwmo.ca

85 NWMO, *Choosing a Way Forward: The Future Management of Canada's Used Nuclear Fuel (Final Study).*

86 *The Future Management of Canada's Used Nuclear Fuel*, p. 146.

fusion is another long-term possibility. Since fusion would be based on lithium and deuterium resources from seawater, the fuel source would have no practical limits. The negative aspects of fusion are significantly lower than for fission, making the fusion option a highly attractive concept. However, there are technical hurdles to overcome and, even if they are overcome, commercial availability is not likely before 2050.[87]

5.4 Biomass Energy

Biomass provides about 10 percent of the world's primary energy supply, and about 22 percent of developing countries' primary energy. For example, the share of biomass from total primary energy supply in Africa is 49 percent, and in India it is 37 percent.[88]

Biomass provides about 10 percent of the world's primary energy supply, and about 22 percent of developing countries' primary energy.

Biomass is either plant-based or animal-based and has a theoretical potential of some 2,900 exajoules, of which just less than 10 percent is considered to be available on a sustainable basis (compared to estimates of current use ranging up to 55 exajoules).[89] Woody biomass comes from forests, with most non-woody biomass being a by-product of agricultural activities. Municipal solid waste may also be used as biomass.

Biomass is renewable in the sense that the forestry and agricultural residues can be grown like crops, and landfills will continue to fill up with municipal waste. Biomass, converted into a liquid fuel (i.e. ethanol or biodiesel), can be used as a transportation fuel. Currently, ethanol is used as a fuel additive in order to reduce emissions and there are already subsidies and other fiscal incentives to increase the ethanol component in gasoline. Biomass can also be used in power generation, either as a liquid fuel, as a gasified fuel, or by straight combustion. Landfill methane is used in a similar fashion as conventional natural gas, except that it must be captured and transported to a power generation plant.

There are a number of problems associated with the large-scale use of biomass, including health problems, land requirements, effects on soil fertility, unfavourable energy balance, and others. However, it is possible that biomass could become a modern source of energy through improvements in conversion technology, and if properly managed, biomass need not make a net contribution to greenhouse gases (GHGs).

5.5 New Renewable Sources of Energy

So-called new renewable energy sources include wind, solar, geothermal, and marine, all of which have insignificant emissions intensity.

87 For a more detailed discussion of these options, see PCAST (US President's Committee of Advisors on Science and Technology) Fusion Review Panel, 1995, US Program of Fusion Energy Research and Development, Washington D.C.

88 Energy Information Administration, *International Energy Outlook 2007*, pp. 492, 512, 518, 526.

89 www.eubia.org/215.0.html

5.5.1 Wind Energy

One of the most widely recognized sources of renewable energy is the wind, a previously expensive means of producing electricity which has declined substantially in cost over the past few decades. Wind energy derives from solar energy, which causes differential heat and pressure effects, producing air movement that results in kinetic energy. While the theoretical potential of wind energy has been estimated at close to 6,000 exajoules, land limitations are believed to limit the actual potential to less than five percent of that amount.[90] Although wind turbines have been used for many centuries to pump water, they have only recently become important to electricity generation. Wind energy potential depends on climate factors, which can change substantially over geographical areas. This makes wind energy similar to geothermal energy, a more location-dependent energy source than biomass. Of course, transmission of wind electricity is possible, but line losses decrease the efficiency of the system.

Wind turbines use the wind to produce electrical power. A turbine with fan blades is placed at the top of a tall tower. The tower is tall in order to harness the wind at a greater velocity, free of turbulence caused by interference from obstacles such as trees, hills, and buildings. As the turbine rotates in the wind, a generator produces electrical power. A single wind turbine can range in size from a few kilowatts (kW) for residential applications to more than five megawatts (MW). Generally, individual wind turbines are grouped into wind farms containing several turbines. Many wind farms are megawatt-scale, ranging from a few megawatts to tens of megawatts. Wind farms or smaller wind projects may be connected directly to utility distribution systems. The larger wind farms are often connected to sub-transmission lines. The small-scale wind farms and individual units are typically defined as distributed generation. Residential systems (5–15 kW) are available; however, they are generally not suitable for urban or small-lot suburban homes due to large space requirements and for aesthetic reasons.

A great deal of research is underway to improve wind turbine technology. Technology improvements already achieved have lowered wind energy costs. Each part of the wind turbine is being subjected to research in order to improve efficiency and reduce costs. Some of the new technology that is being developed uses power electronics to allow for variable rotor speed operation to improve efficiency, control structural loads, and improve power quality. Current wind turbines use generators that can generate electricity only when the turbine's shaft turns at a rate of 1,800 revolutions per minute or greater. However, since a turbine's rotor generally turns at only 60 rotations per minute, it is necessary to increase the rotational speed of the shaft to attain the speed needed for the motor. The airfoils for the wind turbine blades are also being improved to increase energy capture, and improvements have been made to the aerodynamic control devices built into the turbine blades to adjust the aerodynamic driving forces, optimize energy capture, manage loads, and control rotor speed.

5.5.2 Solar Energy

Solar energy may be captured directly using photovoltaic systems, or indirectly from the concentration of energy and thermal conversion through media such as air or water to generate electricity.

Photovoltaic Systems

Solar energy can be transformed through photovoltaic systems to produce electricity directly without intermediate thermal processes. Photovoltaic (PV) systems use semiconductor materials to capture sunlight energy and convert this energy into electricity. The efficiency of conversion is around 40 percent currently, although research is targeting the 85 percent that is theoretically obtainable. Solar energy has come down significantly in terms of cost and has improved efficiencies and reliability over the past few decades. Unlike other renewables, solar energy has long been used (e.g. solar-powered calculators) and is utilized extensively in satellite and communications markets, as well as in remote power and navigational applications. However, for power generation, solar energy is still expensive and unreliable compared to traditional energy sources.

[90] World Energy Council, *New Renewable Energy Resources: A Guide to the Future,* Kogan Page, London, 1994.

Photovoltaic cells, or solar cells, convert sunlight directly into electricity. PV cells are assembled into flat plate systems that can be mounted on rooftops or other sunny areas. They generate electricity with no moving parts, operate quietly with no emissions, and require little maintenance. PV systems are available in the form of small rooftop residential systems (less than 10 kilowatts), medium-sized systems in the range of 10 to 100 kilowatts (kW), and larger systems above 100 kW connected to utility distribution feeders. Again, the cost is currently too high for bulk power applications.

Solar Thermal

Solar thermal power plants use large mirrors to concentrate solar energy toward absorbers. The radiation is used to heat a medium such as air or steam, which then drives a generator to produce electricity. Various technologies are under development to enhance the thermal concentration effect and allow commercial applications. These include parabolic troughs, central receiving towers, and parabolic dishes. These could turn out to be extremely efficient approaches to energy production with relatively low costs. However, relatively inexpensive energy has, until recently, provided a barrier to the research necessary to develop solar thermal. This is changing, and since solar thermal also has the advantage of not contributing to emissions, it is likely that research will advance.

Low-Temperature Solar Energy

A little over 15 percent of the world's energy use is directed at low-temperature heat consumption, about 50 exajoules go into space heating, and 10 exajoules go to water heating. Another 40 exajoules are used as process heat in low- and medium-temperature industrial applications. These uses can, at least in part, be met by low-temperature solar energy. Because the sun does not always shine, all of these applications require some form of energy storage as well.

Overall Solar Potential

The potential for all forms of solar energy is truly enormous, since the amount of solar energy that reaches the earth has been calculated to represent many thousands of times the total primary energy used around the world.[91] However, the diffuse nature of this energy implies a need for substantial technological advances in order for a significant fraction of the potential to be realized.

5.5.3 Geothermal Energy

Geothermal energy is heat stored within the earth. Once captured, such heat can be used for space heating and electricity generation. Similar to conventional fossil fuel resources, geothermal energy requires geological, chemical, and geophysical technology to locate the resource. Geothermal resources have been identified in some 80 countries, with about half of those actually exploiting the opportunity. Jakob Bjornsson has estimated global geothermal resources sufficient to produce 12,000 terawatt-hours of electricity per year.[92] This may be compared to about 44 terawatt-hours currently used in electricity production. Another 38 terawatt-hours from sources where the heat content is too low for electricity is used in direct applications.

So-called new renewable energy sources include wind, solar, geothermal, and marine, all of which have insignificant emissions intensity.

The costs of geothermal energy used in electricity production are in the range of 4.3 to 5.0 cents (Cdn ¢)/kWh.[93] The direct use of geothermal for space heating, greenhouses, spas, and fish farming is generally less expensive, at less than 2 cents per kilowatt-hour. Energy efficiency — around 50–70 percent — is much higher than that associated with other electricity production, which is only 5–20 percent. While the total resource base is enormous, the accessible component is roughly 600,000 exajoules of energy, of which about 1 percent is expected to become economical within 50 years, and 10 percent of that (or some 500 exajoules) within 10 to 20 years.[94]

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91 www.undp.org/eap/activities/wea/drafts-frame.html, p. 162.

92 J. Bjornsson, "The Potential Role of Geothermal Energy and Hydro Power in the World Energy Scenario in Year 2000," proceedings of the 17th WEC Congress, 1998.

93 www.frasermackenzie.com/AlternativeEnergy/Western.pdf

94 J. Bjornsson, "The Potential Role of Geothermal Energy and Hydro Power in the World Energy Scenario in Year 2000," proceedings of the 17th WEC Congress, 1998. p. 255.

5.5.4 Marine Energy

Over two-thirds of the earth's surface is covered by the oceans, and the theoretical energy available from that source is greater than could ever be used. The diffuse nature of the resource, and its distance from where it is needed, reduce its potential usefulness; however, it remains a valuable prospect in many locations. The sources of energy that may be considered include tidal currents, wave energy, ocean thermal energy, and salt gradient energy. Ocean thermal energy could be a prolific source of energy, since it exploits the temperature difference between warm surface water and colder, deep water.

However, just tidal energy has seen limited commercial development to date, although serious work in the area has only been going on for a little over a decade. This remains a potential energy source that requires a lot of research.

5.5.5 Hydrogen

Hydrogen is abundantly available in hydrocarbons and water. Peter Hoffman has dubbed it the "forever fuel," because it produces no harmful carbon dioxide (CO_2) emissions when burned; the only by-products are water and heat.[95] Hydrogen can transport energy over long distances, in pipelines, and then may be used in some form of a fuel cell to drive motion or produce electricity.

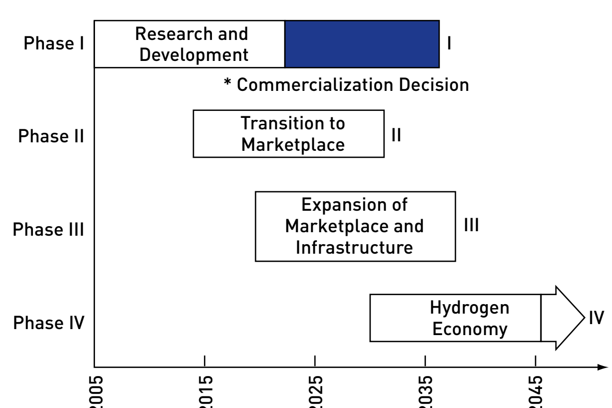
Hydrogen must be extracted either from water or from hydrocarbons. If hydrocarbons are used, the extraction process removes the hydrogen atoms, leaving CO_2 as a by-product, undesirable from a global warming viewpoint if released to the atmosphere. Another way to produce hydrogen avoids fossil fuels by using electrolysis to split water into hydrogen and oxygen. The hydrogen can then be stored and later used in a fuel cell to generate electricity. In a sense, this process is a way to store electricity more effectively than batteries and at a lower cost.

One of the main barriers for developing a hydrogen economy is a low-cost option for producing hydrogen. Currently, most hydrogen is produced from natural gas. Although natural gas will likely provide the earliest affordable feedstock for hydrogen, high natural gas costs are a deterrent. If hydrogen is going to become a realistic option, it needs investment to develop the technology and drive down the costs. To bring down costs, research is underway to develop innovative "breakthrough" technologies for extracting fuel-grade hydrogen from natural gas and coal, as well as producing hydrogen through the use of nuclear energy technology.

A move to reliance on hydrogen also requires advances in the infrastructure for hydrogen energy. This will require improvements in hydrogen storage and transportation techniques. Many countries are participating in the research, with the United States leading the way (the US government spends about $300 million annually on hydrogen and fuel cell research). Other countries actively pursuing research include Canada, Japan, the UK, China, Russia, and France.

Figure 5.4 provides a representation of a possible timeline for the adoption of a hydrogen economy in the United States. This figure indicates that we are far from recognizing the widespread use of hydrogen as an energy source. Phase I highlights the importance of continued research and development into hyrogen-based technology. Phases II and III include the transition from research to the implementation of hydrogen as a viable fuel. Phase II would include small-scale use in the transportation sector, drawing on the existing natural gas and electricity infrastructure. Phase III is the start of the

Figure 5.4
Hydrogen Timeline



SOURCE: United States Department of Energy, Hydrogen Posture Plan, *2004.*

[95] P. Hoffman, *Tomorrow's Energy: Hydrogen, Fuel Cells and the Prospects for a Cleaner Planet,* Cambridge, MA: Cambridge University Press, 2001.

development of infrastructure primarily designed with hydrogen in mind. This would include infrastructure for storage and transportation over wide areas. Phase IV is the final realization of the hydrogen economy. In this phase, infrastructure would span the United States and hydrogen would be available in all regions. Phase IV will not likely be a reality until close to 2030.

5.6 Renewable Energy: Global Summary

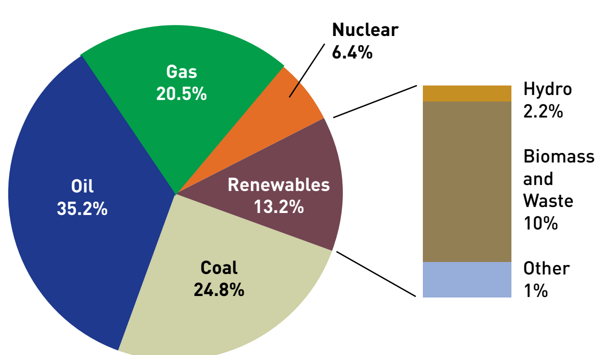
Fossil fuels account for the lion's share of energy used on a global scale. Figure 5.5 shows that for the year 2004, oil accounted for 35.2 percent, coal 24.8 percent, and natural gas 20.5 percent of total primary energy supply. Nuclear contributed 6.4 percent and renewable energy 13.2 percent, with combustible renewable energy (biomass and wastes) continuing to be the dominant renewable. Other renewables and their shares include wind (57 percent), geothermal (39 percent), solar (2.7 percent), and tide/wave (1.3 percent).

As illustrated in Figure 5.6, the growth of renewable sources has been remarkable over the past 14 years particularly for wind, solar and biomass.

Nonetheless, the relative importance of renewable energy on a global scale has not changed appreciably over the last 25 years or so. It remains close to 13 percent of total primary energy supply, and projections on a business-as-usual basis suggest a similar percentage in future (see Figure 5.7).

Figure 5.5

World Primary Energy Supply (11,204 Mtoe) and their Sources, 2004

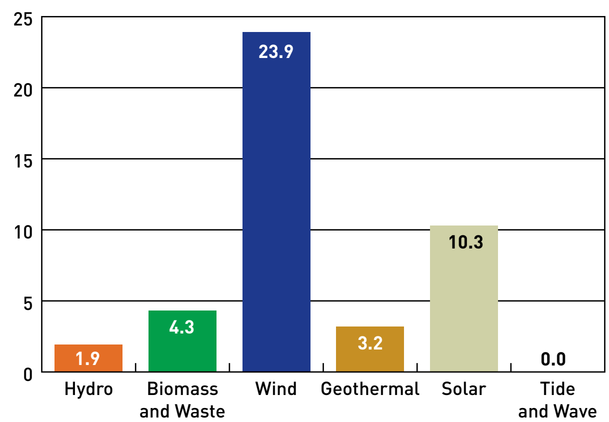


SOURCE: International Energy Agency, World Energy Outlook 2006.

However, it seems likely that renewable energy sources have the potential to play an even greater role in the world energy supply with technical developments and policies that encourage the growth of the renewable market. Table 5.2 provides an estimate of the technical potential for various renewable energy forms, which stands in stark contrast to their current use.

Figure 5.6

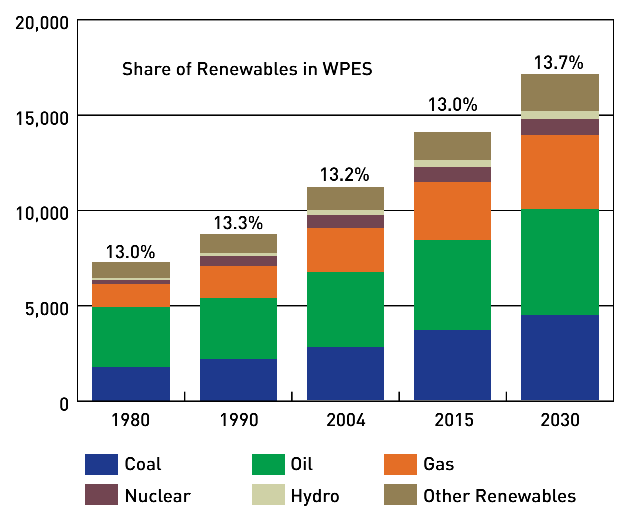
Annual Growth of World Renewable Energy Supply, 1990–2004 (percent)



SOURCE: International Energy Agency, World Energy Outlook 2006.

Figure 5.7

World Primary Energy Supply (WPES) and Share of Renewables (Mtoe)



SOURCE: International Energy Agency, World Energy Outlook 2006.

Table 5.2

Global Renewable Resources Energy Base (exajoules per year)

	Current Use	Technical Potential
Hydro Power	10.0	50
Biomass Energy	50.0	>250
Solar Energy	0.2	>1,600
Wind Energy	0.2	600
Geothermal Energy	2.0	5,000
Ocean Energy	–	–
Total	**62.4**	**>7,500**

SOURCE: T. Johansson, K. McCormick-Brennan, and Neji Lena, The Potentials of Renewable Energy, *March 25, 2004.*

Renewable energy sources are not expected to be economically competitive with fossil fuels in the mid-term without significant support from government policies. Figure 5.8 shows a comparison of generation costs (2003 Canadian cents per kilowatt-hour) for different types of generation technologies.[96]

Renewable technologies are generally characterized by relatively high capital costs and low operation and maintenance costs. As renewables' costs come down and technologies advance, they will become more important. The IEA forecasts the cost reduction to be most significant for solar. In Figure 5.9 we show the range of estimated cost reductions for different renewable technologies.[97]

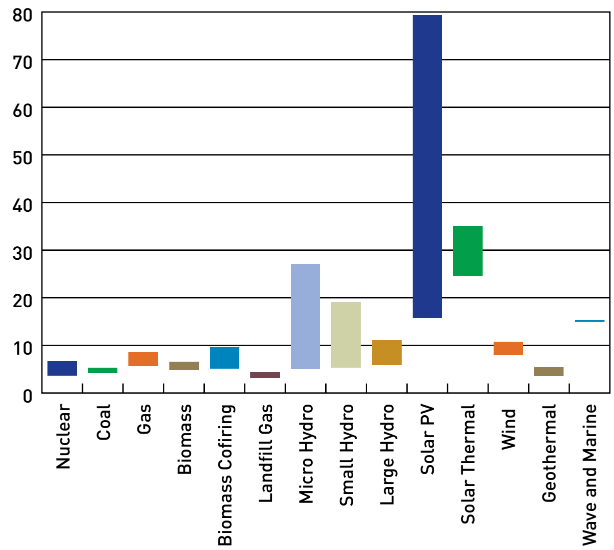
The increasing use of renewable energy sources has important implications for the environment and the economy. Policies promoting the development and use of renewable energy sources and technologies can make a significant difference. The future use of renewable energy resources will depend in part on achieving a balance between economics and

[96] In 2006, CERI updated the relative generation costs of various technologies originally published in 2002 by Pollution Probe (Martin Tampier, *Promoting Green Power in Canada*, Pollution Probe, November 2002).

[97] International Energy Agency, *Energy Technology Perspectives 2006*, p. 232.

Figure 5.8

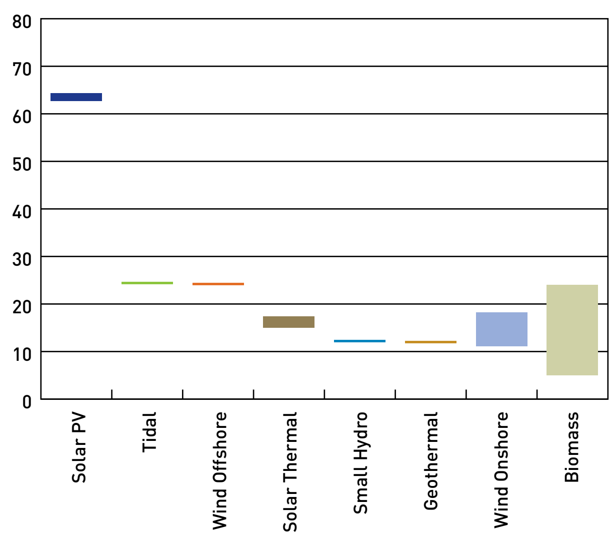
Relative Costs of Electricity Generation Technologies (2003 Canadian cents per kilowatt hour)



SOURCE: CERI, Relative Costs of Electricity Generation Technologies, *September 2006.*

Figure 5.9

Projected Reductions in Capital Costs of Renewable Energy Technologies, 2004–2030 (percent)



SOURCE: International Energy Agency, Energy Technology Perspectives 2006.

environmental impacts of non-renewable resources such as greenhouse gas (GHG) emissions. The current and future availability of cheap fossil fuels will continue to be a barrier to the expansion of the role of renewable energy. While hydro power has been reasonably well-developed in most countries, there remains considerable potential in others. Nuclear power has been stalled for a number of reasons that seem to be fading in importance. Because nuclear power provides one of the few emissions-free sources that could be deployed on a large scale relatively quickly, it remains a legitimate option to consider in meeting specific future needs.

5.7 The IEA Outlook to 2025 — CO_2 Emissions

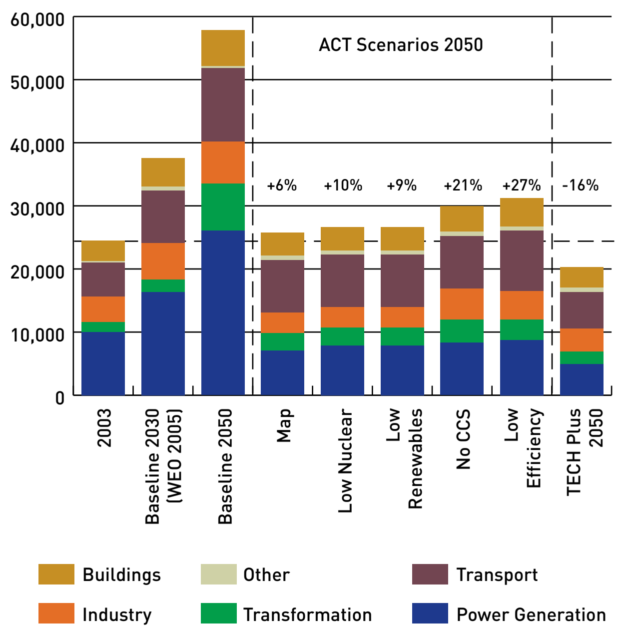
The 2006 International Energy Agency report, *Energy Technology Perspectives*,[98] shows that the world cannot reach sustainable energy under the base scenario (assumptions of scenarios presented in Section 2.2.2). Global CO_2 emissions are projected to rise by an unsustainable 137 percent from 24.5 gigatonnes (Gt) in 2003 to 58 in 2050 (Figure 5.10). The global carbon intensity increases mainly due to greater reliance on coal for power generation and production of liquid transport fuel.

From 2003 to 2050, oil demand is projected to increase by 93 percent, natural gas by 138 percent and coal by 192 percent.

Under the Accelerated Technology (ACT) scenarios, significant CO_2 emission reductions will be achieved by using current technology and other technologies which

Figure 5.10

Comparison of CO_2 Emissions among Alternative Scenarios, 2003–2050



SOURCE: International Energy Agency, 2006, Energy Technology Perspectives, *p. 46.*

[98] IEA, 2006, *Energy Technology Perspectives — Scenarios & Strategies to 2050, accessed at* www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1693

Table 5.3

Electricity Generation Shares in the Baseline, ACT and TECH Plus Scenarios, 2050

		ACT Scenarios					
	Baseline	Map	Low Nuclear	Low Renewables	No CCS	Low Efficiency	TECH Plus
			(percentage)				
Coal	47.1	26.9	30.4	29.5	16.5	27.6	20.9
Coal	47.1	12.6	14.3	13.3	16.5	12.4	5.7
Coal CCS	0.0	14.3	16.1	16.2	0.0	15.2	15.2
Oil	3.3	2.3	2.3	2.2	2.0	2.0	2.2
Gas	27.6	22.6	25.7	26.9	28.2	25.4	19.5
Nuclear	6.7	16.8	9.8	18.0	19.0	16.0	22.2
Hydro	9.5	15.4	15.5	14.0	16.0	13.4	15.3
Biomass	2.0	4.5	4.6	3.0	4.8	4.4	5.1
Other Renewables	3.9	11.4	11.8	6.4	13.5	11.2	14.8
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

SOURCE: International Energy Agency, 2006 Energy Technology Perspectives, *p. 52.*

could become commercially available in the next two decades. Under the ACT Map, CO_2 emissions by the end of the projected period will be 6 percent higher than in 2003. Under the other four ACT scenarios, CO_2 emissions will be 9 to 27 percent higher than in 2003.

Under TECH Plus, CO_2 emissions stabilize at about 16 percent below current levels. Hydrogen and biofuels provide 34 percent of total final transportation energy demand in 2050; primary oil demand in 2050 would equal the present level.

It should be noted that from 1973 to 1985, the oil price shocks reduced the global share of carbonization of electricity supply from 75 percent to 64 percent. The decarbonization of electricity supply was mainly due to the rise of nuclear power, which increased from 3.3 percent to 15 percent. From 1985 to 2003, the combined growth rate of nuclear and renewables limited the share of global carbonization of electricity supply to 65.9 percent.

Under the ACT scenarios the IEA observes substantial decarbonization of electricity supply as the power generation mix shifts towards nuclear power, renewables, natural gas, and coal with CO_2 Capture and Storage (CCS).

Table 5.3 illustrates the energy mix in electricity generation by the end of the projected period. Under the ACT Map, nuclear power contributes about 16.8 percent of electricity generated in 2050. In the same year, nuclear power accounts for 1,922 Mt of CO_2 saving in comparison to the baseline. Under the remaining four ACT scenarios, the share of nuclear in the decarbonizing of electricity generation or reduction of CO_2 emissions in comparison to the baseline varies from 593 Mt to 2,928 Mt.

The TECH Plus scenario is more optimistic about cost improvements of technologies. Under this scenario, the share of nuclear in the generation mix exceeds 22 percent and nuclear power accounts for 2,677 Mt of CO_2 reduction in comparison to the baseline.

6 NORTH AMERICAN

Energy Outlook and Issues

As has been indicated in previous chapters, North America is an important region for energy, producing about 20 percent of global energy supply and consuming about 25 percent of the world's primary energy. In North America, there is concern over an assortment of future energy issues, including availability of local energy resources, extent of remaining reserves, security of future supply, adequacy of infrastructure for delivering energy to markets, continuing growth in the demand for energy, and the environmental repercussions associated with supplying energy. In addition, there are many local issues that affect particular energy sectors and specific geographical regions of North America.

It is noteworthy that almost 30 percent of US energy consumption is currently met by net imports, and it is expected that imports will comprise 32 percent by 2030.[99] North American energy markets are becoming increasingly integrated. Both Mexico and Canada are net exporters of energy to the US. Most of Mexico's oil exports go to the US, while Canada exports significant amounts of its electricity, natural gas, and crude oil production to the US.[100] The US, for its part, exports coal to Canada, and provides gas and refined petroleum products to Mexico. With growing world energy demand, North America also faces challenges in securing supplies from overseas. We consider energy trade flows, within and outside North America, in more detail in Sections 6.1 and 6.2.

6.1 Demand, Prices, and Sustainability

The variety of North American energy issues can be grouped into three main themes:

- Growing demand and security of supply
- High and volatile energy prices
- Achieving sustainability

[99] Energy Information Administration, *Annual Energy Outlook 2007 with Projections to 2030,* Washington, D.C., January 2004.

[100] US and Canadian electric systems are increasingly integrated, with flows of power moving from country to country depending on the time of day and water levels in the hydro systems.

6.1.1 Growing Demand and Security of Supply

Despite its vast reserves of energy, North America, specifically the US, is an energy-importing region. As a result of political instability in countries that export to North America (especially in the Middle East), there is concern in the US over dependence on unstable supply sources and possible supply disruptions.

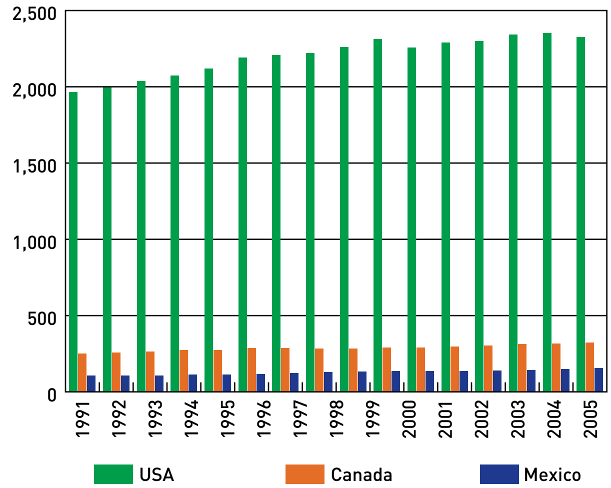
North American primary energy consumption increased by an average of 1.3 percent per year from 1996 to 2006.[101] As clearly shown in Figure 6.1, the United States is the major contributor to energy demand.

As illustrated in Figure 6.2, there are distinct differences in the primary energy mix among Canada, Mexico, and the US. The US relies on fossil-based fuels for almost 90 percent of its primary energy needs (40.4 percent from oil and 24.4 percent apiece from gas and coal). While the contribution of nuclear power remained fairly stable at around 7 percent between 1990 and 1997, its share had increased to more than 8 percent by 2002. This one percentage point share increase masks the fact that, while the country's total energy consumption increased at an annual average rate of 0.8 percent between 1997 and 2006, nuclear energy consumption grew at a much higher average rate of 2.4 percent per year over the same period, recovering from a period of diminished output. This increase was a consequence of higher output at existing plants, as no new units came into service over the period.

In Canada, hydro power plays a more important role than in the US or Mexico. Some 25 percent of Canada's energy requirements are met by hydro power (in contrast to 3 percent and 4 percent for the US and Mexico, respectively). Despite having abundant coal reserves (reserves/production ratio of 105 years),[102] coal contributes only 11 percent of Canada's total energy consumption, less than half of that of the US percentage. Natural gas comprises about 27 percent of Canada's primary energy mix. This proportion is similar to that of the US and Mexico. As a consequence of the high hydro usage, Canada relies on fossil fuels for

Figure 6.1

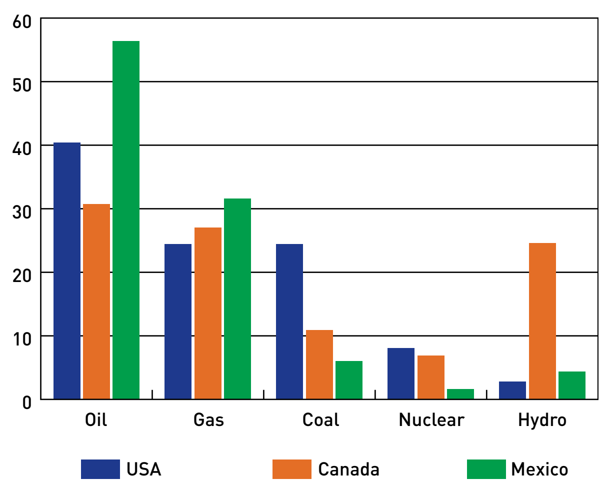
North American Primary Energy Consumption, 1991–2006 (million tonnes of oil equivalent)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

Figure 6.2

Primary Energy Consumption Shares by Fuel, 2006 (million tonnes of oil equivalent)



SOURCE: British Petroleum Company, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

[101] Primary energy consumption includes oil, natural gas, hydroelectricity, nuclear, and coal.

[102] British Petroleum Company, *BP Statistical Review of World Energy 2003,* London, United Kingdom, 2003.

Table 6.1
GDP and Energy Consumption, 2004

	Population (millions)	GDP (US$ billion)	Energy Use (Mtoe)	GDP per Capita (US$)	Energy Use per Capita (toe)
US	293	10,704	1,602	36,414	5,449
Canada	32	787	202	24,200	6,205
Mexico	104	619	102	5,952	977
North America	**430**	**12,110**	**1,905**	**28,132**	**4,426**

SOURCE: IEA/OECD, Energy Balances of OECD Countries 2003-2004*, 2006.*

NOTES: GDP figures are in US dollars of year 2000 purchasing power; Mtoe: million tonnes of oil equivalent; toe: tonnes of oil equivalent.

69 percent of its primary energy needs, and has arguably the most diverse energy mix in comparison to the US (approximately 89 percent) and Mexico (about 93 percent).

Of the three North American Free Trade Agreement (NAFTA) partners, Mexico is by far the most dependent on oil and gas. Almost 90 percent of its primary energy consumption is based on oil and gas, compared to 65 percent for the US and only 58 percent for Canada. The trend since the mid-1960s shows a stable share of natural gas in Mexico's primary energy mix, a decrease of four percentage points for hydro, and increases in the percentages derived from oil, nuclear, and coal.

In Table 6.1 we consider gross domestic product (GDP) and energy use, in total and on a per capita basis. Energy consumption is normally closely linked to economic prosperity (one measure of which is GDP). While the US clearly leads in terms of GDP per capita, Canada has the highest per capita energy consumption. The reasons for this include differences in weather, a relatively small population dispersed over a large land area, and an energy-intensive resource base. GDP annual growth rate projections between 2000 and 2010 are: Canada 2.5 percent, Mexico 4.0 percent, and the United States 2.9 percent.[103] The forecasted increase in population and economic growth is projected to cause an annual energy consumption increase of 1.7 percent for North America.[104]

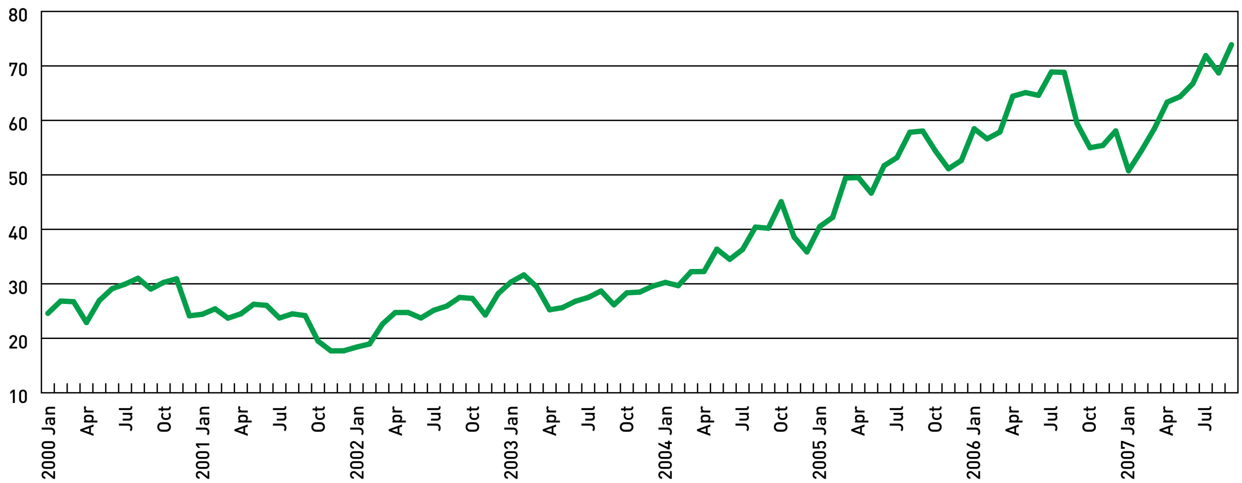
As noted earlier, much US energy consumption is currently met by imports — almost 30 percent of the total — and this is expected to grow despite increasing

[103] North American Energy Working Group, *The Energy Picture*, June 2002.

[104] International Energy Agency, *World Energy Outlook 2006*, Paris, France, 2007.

Figure 6.3

OPEC Reference Crude Basket Price — Monthly Average — January 2000–September 2007 (US$ per barrel)



SOURCE: Organization of Petroleum Exporting Countries (OPEC) various publications and web site at www.opec.org/home/basket.aspx

NOTE: September 2007 average includes daily prices up to September 26, 2007.

integration of North American energy markets.[105] Almost half of the oil produced in Mexico is exported to the US, for example. On a gross basis, Canada exports more than half of its natural gas and crude oil production to the US, as well as significant amounts of electric power.[106] The US exports coal to Canada and smaller quantities of gas and refined petroleum products to Mexico. Despite this integration, ever-growing world energy demand dictates that North America will need to continue to secure supplies from overseas.

6.1.2 High and Volatile Energy Prices

Crude oil prices rose from under $20 per barrel in the late 1990s to about $35 per barrel in early 2003 and have more than doubled since then, with the WTI price recently exceeding $70 per barrel. These movements were caused by several factors including the Iraq conflict, situations in Venezuela and Nigeria, and to some extent the falling US dollar. Figure 6.3 depicts the average monthly OPEC reference crude price from 2000 to the present.

Natural gas prices have also increased, and are now more volatile than in the past. Wellhead natural gas prices have been trending upwards, averaging $6.42 per million cubic feet (Mcf) in 2006 compared to $1.71/Mcf in 1990.[107] The growth of gas-fired generating capacity has led to greater volatility of gas prices and a closer relationship between gas and electricity prices.

Higher fuel prices and increased volatility in those prices have affected investment. High prices have made some investment opportunities more profitable; increased volatility has made the rewards of investment less certain. For example, the possibility of sustained high natural gas prices stimulates exploration and production while discouraging consumption in non-residential uses. Higher and more volatile prices have also affected residential consumers, in some cases prompting political intervention.[108] Higher prices for natural gas promote conservation and energy efficiency, and provide incentives to seek alternative sources of energy.

[105] Energy Information Administration, *Annual Energy Outlook 2004 with Projections to 2025,* Washington, D.C., January 2004.

[106] Statistics Canada, *Report on Energy Supply-Demand in Canada*, Catalogue No. 57-003-XIB.

[107] Energy Information Administration, accessed at http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm

[108] For example, price caps on residential electricity rates in Ontario and gas rebates in Alberta.

For some energy-intensive industries, high natural gas prices have resulted in pressure to relocate outside North America. This is a particular issue for the petrochemical industry, which uses a large quantity of natural gas as a feedstock.

6.1.3 Achieving Sustainability

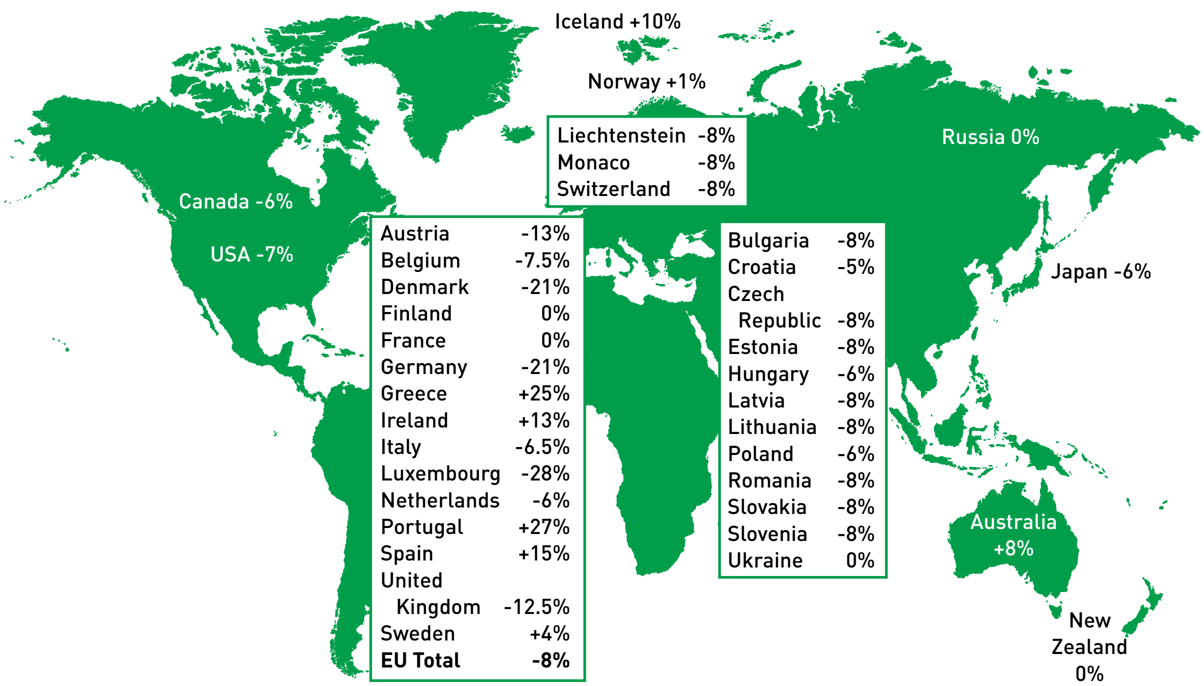
As was illustrated in the previous chapter, there is an uneven distribution of carbon emissions associated with various energy types, which is very much correlated to industrialization. Examination of the contribution of the various fuels to emissions suggests that the use of coal in Asia and of both coal and oil in North America and Europe accounts for most of the world's carbon dioxide emissions.

Looking into the future (2030), the countries of Asia, the Middle East, Africa and Latin America are expected to generate the largest percentage increases in carbon dioxide emissions, roughly doubling from the year 2003. OECD North America follows with an expected 43 percent increase, compared to 20 percent for OECD Europe.[109]

These forecasts reflect in part the Kyoto Protocol standards (see Figure 6.4). Not all the countries have agreed to the standards. Among those that have, Japan and Canada agreed to reduce emissions by 6 percent.

[109] Energy Information Agency, *International Energy Outlook 2006*, accessed at www.eia.doe.gov/oiaf/ieo/pdf/ieoreftab_10.pdf

Figure 6.4
Kyoto Protocol Standards (percent reduction in emissions)



SOURCE: Fact Sheet #12 accessed at www.acidrain.org

This has important implications for how Canada will meet its energy needs in the coming decade. It now seems unlikely that Canada will meet this commitment, which would have required a combination of faster growth in renewable energy supply, more vigorous conservation measures and perhaps a commitment to nuclear expansion.

6.2 North American Options

6.2.1 Outlook for Oil and Gas Consumption

North America and Asia Pacific each accounted for almost 30 percent of world demand in 2006.[110] Oil consumption in the transportation sector currently represents 74 percent of North America's total oil demand,[111] consisting mostly of gasoline, jet fuel, and diesel, the lighter components of the crude barrel. That share is expected to continue to rise as oil use declines in other end-use sectors. In the US, the transportation sector accounts for 77 percent of the country's total energy consumption and produces almost one-third of its carbon dioxide (CO_2) emissions. The US transportation sector is 96 percent dependent on petroleum.

Demand growth in North America is focused on lighter-end gasoline and diesel. This poses a challenge to refineries to invest in upgrading/conversion facilities so as to maximize their flexibility to process a diverse (and least-cost) crude slate while satisfying demand for a lighter cut of the barrel.

Mexico's long-term energy demand will be driven principally by economic growth. The US Energy Information Administration (EIA) projects a strong 3.6 percent per year GDP growth to 2030,[112] aided by Mexico's proximity to the US economy and its participation in NAFTA. Consequently, it leads the US and Canada in oil, gas, and coal demand growth.

110 British Petroleum Company, *BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.

111 International Energy Agency, *Energy Balances of OECD Countries — Extended Energy Balances Vol. 2007 Release 01*, accessed via SourceOECD.

112 The Energy Working Group projects 4 percent growth from 2000 to 2010 (see Section 6.1.1 above).

Table 6.2 summarizes the EIA's long-term forecast of GDP and energy demand growth for the US, Canada, and Mexico.

Because of higher experienced and expected natural gas prices, coal and hydro are now projected to be the fastest growing components of primary energy consumption in North America. Except in the Americas, OECD Asia and the Middle East, the EIA expects natural gas to have the highest growth rate to 2030 among the primary energy forms. Most of the increase in natural gas consumption is expected to be for electricity generation, but the most recent EIA forecasts have reduced the expectations of growth in gas-fired generation on this continent as rising gas prices make clean coal technologies more competitive.[113] Even so, the percentage of electricity generation from natural gas is expected to rise. Alberta's oil sands have also been pegged as a significant area of natural gas demand growth.

Rapid growth in natural gas use from a low base is projected by the EIA for Mexico, at an annual rate of 3.4 percent to 2030. Its industrial and electric utility sectors are expected to account for most of the growth. Even though gas production is expected to double (PEMEX being constrained by the availability of government funding), it will not keep pace with rising consumption, so Mexico will become increasingly dependent on natural gas imports.

6.2.2 Resource Base and Supply Outlook

6.2.2.1 Conventional Crude Oil

Conventional crude oil reserves in Canada's Western Canada Sedimentary Basin (WCSB) are in decline. Proven reserves in Canada amounted to 6.9 billion barrels at of the end of 2006, representing 10.1 years of production at current rates.[114] Production from the East Coast offshore peaked in 2003 and declined thereafter, although 2007 output appears likely to set a new record, with expansion at White Rose and Terra Nova returning to full production. Assuming that negotiations between producers and the government of Newfoundland and Labrador bear fruit, there could be a boost to conventional oil output with the start-up of the Hebron oil field.

Reserves/production ratios of 7.1 and 9.1 years for the US and Mexico, respectively, are somewhat lower than for Canada's conventional oil. US output is expected to continue its slow secular decline.

Mexico produced about 3.7 million daily barrels of crude in 2006. The expectation is that it will ultimately adopt policies to encourage the efficient development

Table 6.2

GDP and Primary Energy Consumption Growth Forecast, by Source (Average Annual Percentage Growth, 2004–2030) — Reference Case

	GDP	Total Energy	Oil	Gas	Coal	Nuclear	Hydro
US	2.9	1.0	1	0.6	1.6	0.5	1.4
Canada	2.3	1.2	0.2	1.7	1.6	1.5	1.4
Mexico	3.6	2.3	1.6	3.4	3.8	0.9	2.3
North America	**2.9**	**1.1**	**1.0**	**1.4**	**1.6**	**0.6**	**1.5**

Source: Energy Information Administration, International Energy Outlook 2007*, Appendix A, accessed at www.eia.doe.gov/oiaf/ieo/pdf/0484(2007).pdf*

113 The EIA's *Annual Energy Outlook 2007* (Reference Case) forecasts that the natural gas share of electricity generation in the US will increase from 16 percent in 2004 to 19 percent in 2020; then gas-fired electricity output begins to decline.

114 Statistics Canada, *Oil and Gas Extraction*, Catalogue No. 26-213-XIE.

of its resource base, but first its output will decline to 3.0 million barrels per day by 2015, and start to recover thereafter.

6.2.2.2 Canadian Oil Sands

Canada's bitumen resources in Alberta's oil sands represent one of the world's largest hydrocarbon deposits. The Alberta Energy and Utilities Board (AEUB) places remaining established reserves of crude bitumen in Alberta at 173 billion barrels as of the end of 2006.

In its latest assessment of the oil sands supply outlook,[115] CERI concluded that most oil sands projects will be economically attractive as long as the equivalent West Texas Intermediate (WTI) oil price at Cushing[116] stays above US$52 per barrel. Although oil prices are generally expected to decline from the current US$70 per barrel range, forecasters generally anticipate that they will stay above US$50. Under this assumption, CERI projects production (of marketed crude bitumen and synthetic crude oil) to increase realistically from 1.2 million barrels per day in 2006 to 4.3 million barrels per day by 2027. Production could be as high as 5.3 million barrels by 2027 if not constrained by factors such as the availability of skilled labour and the ability of the Alberta economy to absorb the huge investments involved.

The oil sands industry faces a number of development issues and potential constraints.

- Availability of natural gas in rapidly decreasing quantities
- Environmental and water management issues
- Capital costs and labour shortages
- The competing interests of both oil and gas rights holders (the "gas-over-bitumen" issue)

Gas Use in the Canadian Oil Sands Industry

Oil sands operations require significant energy inputs, in particular natural gas for steam generation and hydrogen production. The growth of the oil sands industry has already resulted in its gas demand exceeding 1 billion cubic feet per day in 2005. This consumption can be compared to the ultimate

[115] Canadian Energy Research Institute, *Oil Sands Supply Cost and Production Outlook, 2007-2027* (forthcoming).

[116] WTI is a grade of crude oil that has its main delivery point in Cushing, OK. The spot price for WTI delivered at Cushing is the ultimate settlement price for the NYMEX oil futures contract.

capacity of 1.2 billion cubic feet per day for the proposed Mackenzie Delta pipeline, which could be available in stages beyond 2011, should the proposed pipeline be constructed.

The oil sands industry is actively seeking to improve energy efficiencies. However, if alternative energy sources are not found to replace natural gas, incremental gas consumption by the industry could have a significant impact on the balance of natural gas supply and demand, resulting in upward pressure on prices.

In addition to seeking efficiency improvements in energy use, the oil sands industry is increasingly looking at alternatives to natural gas as an external source of energy and as a means to satisfy its hydrogen requirements. One option is coal, of which there are abundant reserves in Alberta. Although coal gasification represents a proven technology, it would result in increased greenhouse gas (GHG) emissions and is not cost effective. A second option being explored is the use or combustion of the heavy ends of the bitumen barrel; however, this suffers many of the same challenges as coal. A third alternative would be to use nuclear generation as a source of energy (for heat and/or electric power) and possibly hydrogen, but the nuclear option presents both technical and political challenges.

Environmental and Water Management Issues

Bitumen production has considerable environmental impact, whether by in situ or mining methods as, to a somewhat lesser extent, does upgrading.[117] Surface disturbance is extensive; water consumption is significant; air and water emissions are substantial. Current technologies result in large GHG emissions. The industry is working hard to mitigate these impacts, but concern about environmental impacts remains.

Although a detailed assessment of the economic costs of Kyoto compliance has yet to be made, independent surveys of several oil sands operators have concluded that costs will range between 30 and 80 Canadian cents per barrel of bitumen produced. Other sources have claimed that costs could be as high as C$3 per barrel.[118]

Water is also an integral part of oil sands operations.[119] Typically, water requirements range between 2.5 to 4 cubic metres (m^3) of water for each cubic metre of bitumen produced, although some of the water is recycled. Water use remains an issue in the oil sands. New recovery technologies have the potential to reduce water use substantially.[120]

The oil sands industry is increasingly looking at alternatives to natural gas as an external source of energy and as a means to satisfy its hydrogen requirements.

Capital Costs and Labour Shortages

The industry has recently experienced substantial capital cost overruns, particularly on large integrated mining, extraction, and upgrading developments. Given the sensitivity of project economics to cost overruns, completing projects on budget and on time presents a challenge to future oil sands development.

The high level of development and construction activities has resulted in an acute shortage of skilled labour in the Fort McMurray area. The consequent use of a less-than-qualified workforce has been blamed for

[117] Oil sands development occurs in two broad categories: mining activity is used when the resource is near or at the surface, whereas in situ is used in cases where the resource is deep and requires drilling to recover. The various technologies are described in R.B. Dunbar, M. Stogran, P. Chan, and S. Chan, *Oil Sands Supply Outlook: Potential Supply and Costs of Crude Bitumen and Synthetic Crude Oil in Canada, 2003-2017,* Study No. 108, Canadian Energy Research Institute, March 2004.

[118] "Kyoto Ratification to Have Limited Effect on Alberta Oil Sands," *Alexander's Gas & Oil Connections*, Volume 8, Issue 23, November 27, 2003.

[119] Water is used for muskeg drainage, overburden and formation dewatering, water flow diversion for mining operations, to make up water for steam generation in cyclic steam stimulation and steam-assisted gravity drainage operations, and to provide water for hydro transport.

[120] For example, VAPEX (vapour extraction), which uses solvents to reduce bitumen viscosity in situ, THAI (toe-to-heel air injection), which uses air injection and subsurface combustion to increase mobility in the reservoir, and various thermal/solvent hybrids have the potential to reduce water consumption significantly.

the loss in productivity. The efficient assembly, deployment, and supervision of work crews are issues that need to be addressed by industry, labour unions, and government.

Infrastructure Constraints

The economics of additional cogeneration from oil sands developments are affected by the electricity transmission infrastructure in Alberta. This, in turn, has an impact on the economics of bitumen recovery. The current transmission capacity from Fort McMurray is limited, effectively preventing the export of power to other areas of Alberta. Limited interconnection with BC and Saskatchewan also constrains potential provincial exports.

Additional crude oil export capacity from Alberta will be necessary from as early as 2009. Export capabilities out of the oil sands and Alberta have implications for the US market, refining availability, and the choice between exporting bitumen or local upgrading to synthetic crude. For further discussion of refining capacity, see Appendix A.

Gas over Bitumen

A long-standing issue for the in situ oil sands industry is related to the production of natural gas that is associated with crude bitumen reserves. This issue is not expected to ultimately impede in situ development; however, finding a solution is proving difficult and has consumed substantial industry, regulatory, and government resources.

6.2.3 Natural Gas

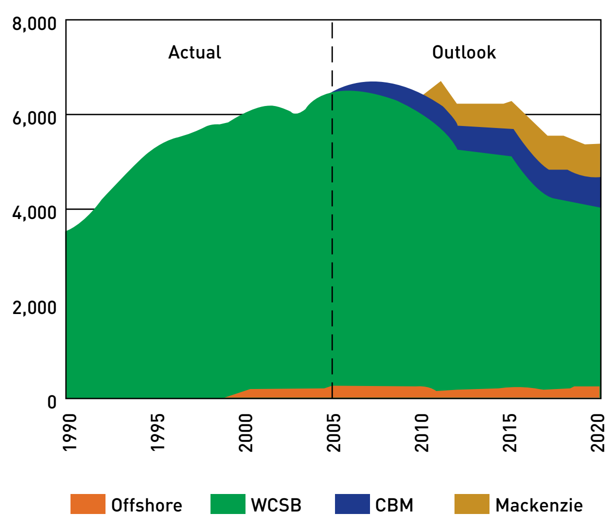
US proven gas reserves increased by 6 trillion cubic feet between 2001 and 2002; however, with production of 52.1 billion cubic feet per day (or 19 trillion cubic feet per year), the reserves increase represents less than half of one year of domestic production, and the reserves/production ratio stood at 9.6 years as of the end of 2002. At 60 trillion cubic feet, Canadian reserves increased by less than 1 trillion cubic feet in 2002 (giving a reserves/production ratio of 9.3 years). In Mexico, PEMEX revised its estimate of national oil and gas reserves downward in September 2002 to comply with US Securities and Exchange Commission filing guidelines. Consequently, Mexico's estimated reserves dropped by nearly 21 trillion cubic feet (or 70 percent).

The EIA forecasts that US production will grow, due to expansion of coal bed methane (CBM) output and the construction of a gas pipeline linking the Alaska North Slope to the "lower 48". Even so, US supply growth will not keep pace with domestic consumption. Consequently, much of the demand growth will be met by rising LNG imports.

6.2.3.1 Natural Gas Outlook

Conventional production in the Western Canada Sedimentary Basin (WCSB) has begun to decline, and is being offset by rising coal bed methane output. Although the deeper, higher-quality gas regions of the WCSB could still produce some prolific wells, the basin is relatively mature and these deeper, larger pools are becoming harder and more expensive to find. Modest increments to Canadian conventional gas production are expected in Newfoundland and Nova Scotia offshore, with larger amounts becoming available if and when the proposed Mackenzie Valley pipeline is built. Figure 6.5 presents the Reference Outlook of Natural Resources Canada, with gas via the Mackenzie Valley pipeline shown separately. CERI believes that this outlook is broadly correct, except that it now appears doubtful that the Mackenzie Valley pipeline will be in service by 2011 as contemplated by Natural Resources Canada.

Figure 6.5
Canadian Natural Gas Supply, 1990–2020



SOURCE: Natural Resources Canada, Canada's Energy Outlook: The Reference Case 2006, *Figure US2.*

Developments on Canada's east coast offshore and in British Columbia (both in the northeast of the province and, longer term, on the west coast offshore) hold some promise in helping to offset declining production in the rest of the WCSB. Although the higher gas prices experienced in recent years have revived interest in the supply potential of natural gas from Canada's High Arctic, a number of LNG terminals have been and are being constructed in North America, leading to fears that delays in moving the Mackenzie Valley pipeline project forward may result in a lost opportunity. Drilling in the 1970s and 1980s in the Sverdrup Basin (Nunavut) identified 16 trillion cubic feet (tcf) of discovered reserves. Concepts for development in the 1980s were abandoned when natural gas prices fell in the latter half of the decade and remained low throughout the 1990s.

Additional gas supply could be available from coal bed methane (CBM) deposits in western Canada. CBM deposits exist mainly in Alberta and British Columbia. The amount of gas available in the coal seams depends on numerous factors including rank, quality, composition, thickness, depth, and permeability. CBM development is still in its infancy in Alberta, but Natural Resources Canada estimates that Alberta's coal bed methane in place amounts to 500 tcf, compared to 95 million tcf (remaining) in place for conventional natural gas.

In summary, other sources of gas in Canada include production from Canada's offshore east coast, the North and CBM. Supply from CBM, the east coast offshore and Mackenzie Delta will make up for some of the decline in WCSB conventional gas. However, even with all of these expected additional sources, gas supply in Canada is expected to decline year-over-year, interrupted by up-ticks as the Mackenzie Valley pipeline is built or expanded.

6.2.4 Supply/Demand Balance and Petroleum Trade

6.2.4.1 Oil

In 2006, net crude oil imports by the US amounted to 10.1 million barrels per day,[121] or 66 percent of domestic oil consumption. Because of difficulties in achieving expansions of refining capacity, the US has also become a significant importer of refined petroleum products. In 2006, US imports of oil and oil products taken together amounted to 13.6 million barrels per day. Imports of crude and products from Canada totalled 2.3 million barrels per day, the largest of any country exporting to the US. Figure 6.6 identifies oil and products imports to the US by country of origin.

In its 2007 energy outlook,[122] the Energy Information Administration (EIA) projects that by 2030, net petroleum imports by the US will increase to 71 percent of consumption, with OPEC nations accounting for 37 percent of the rise in US petroleum imports. The EIA also forecasts that output of oil derived from Canada's oil sands will rise from 1.1 million barrels per day in 2004 to 3.6 million by 2030.

In Canada, refiners compete for crude with their US counterparts, particularly those in the Midwest around the Chicago/Wood River/Patoka area. With hardware configurations that have the flexibility to process a diverse crude slate, and with supply options that include crude imports entering the US via the Gulf Coast, US PADD II refiners generally have some advantage over Canadian refiners in terms of feedstock flexibility. Large-scale oil sands development will test the limits of PADD II refineries to handle SCO and diluted bitumen, creating a need for expanded ability to process these crudes. Where any new refinery capacity should be located, and how it should be configured, are not simple matters. To date, increased refinery capacity has been by modification to existing facilities. No new greenfield capacity has been added to North American refining since the 1980s. See Appendix A for a brief description of oil refining in North America.

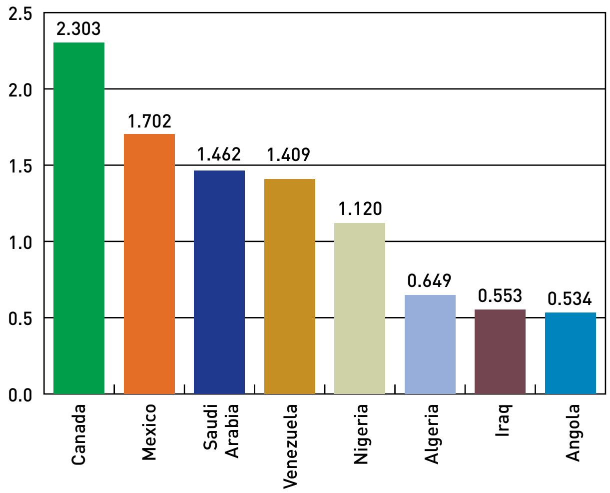
6.2.4.2 Natural Gas

In the US, growing natural gas production is not expected to keep pace with rising consumption. Consequently, imports are expected to increase. In 2006, the US imported 4.2 trillion cubic feet (tcf) of gas (3.6 tcf and 0.6 tcf by pipeline and through LNG shipments, respectively) to satisfy 19 percent of its domestic consumption of 22 tcf. It is significant to note

121 www.eia.doe.gov/emeu/aer/txt/ptb0504.html

122 Energy Information Administration, *International Energy Outlook 2007*, Washington, D.C., 2007.

Figure 6.6
Major US Oil Imports from Leading Countries of Origin, 2006 (million barrels per day)



SOURCE: US Energy Information Administration, accessed at http://tonto.eia.doe.gov/dnav/pet/xls/pet_move_impcus_a2_nus_ep00_im0_mbblpd_m.xls

that in its latest forecast[123] of US gas imports, the EIA forecasts dramatic declines in imports of natural gas from Canada, and dramatic increases in imports of LNG from offshore, the latter exceeding the former by 2015. The decline in gas imports from Canada is attributed to a projected increase in Canadian gas consumption, particularly in the oil sands, and a decline in gas production from Canada's traditional producing areas.

Total net imports of natural gas into the US are projected to increase from 4.2 tcf in 2006 to 5.5 tcf in 2030. Rising liquefied natural gas (LNG) imports are slated to come from various African, Asian, and South American sources. US interest in LNG has been strengthened as a result of sustained high natural gas prices and declining costs throughout the LNG supply chain (production, liquefaction, transportation, and regasification).

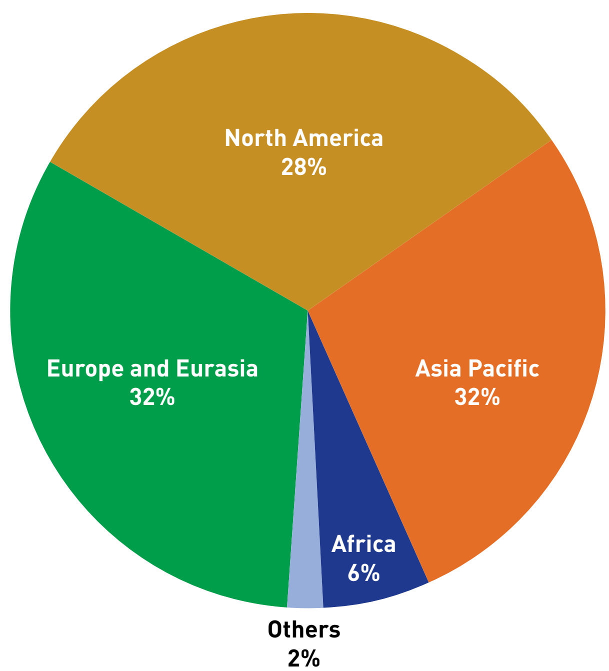
LNG is becoming an increasingly important energy source for many countries, including the US. As the world market for LNG continues to expand, natural gas is expected to become more of a global commodity.

There are currently many proposals for the expansion of existing, and the addition of new, LNG terminals in the US, Canada, and Mexico. It appears that many of these facilities may not come to fruition; not all of them appear to be needed and many may not receive the required regulatory approval.[124] The evolution of the pipeline sector has played a critical role in the penetration of natural gas in North American markets. A brief discussion of this evolution is set out in Appendix B.

6.2.5 Coal

Coal accounts for 57 percent of the world's proven reserves of fossil fuels, and global coal reserves represent 147 years of production at current rates.[125] North America has 28 percent of the world's coal reserves (see Figure 6.7).

Figure 6.7
World Coal Reserves as of Year-end 2006



SOURCE: British Petroleum, BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.*

[123] Energy Information Administration, *Annual Energy Outlook 2007.*

[124] LNG imports to the US come from Trinidad and Tobago, Oman, Qatar, Algeria, Nigeria, Brunei, and Malaysia. There are five LNG facilities in the United States, Canada, and Mexico; a number of others have received regulatory approval.

[125] Canada, the US and Mexico have reserves/production (R/P) ratios of 105, 234 and 109 years respectively, according to British Petroleum Company's *BP Statistical Review of World Energy 2007*, London, United Kingdom, 2007.

The main barriers to increased coal use relate to environmental concerns regarding emissions. Advanced coal technologies exist that are capable of almost entirely eliminating criteria pollutants from coal-fired power generation, namely particulates, oxides of nitrogen, and sulphur dioxide. Coal-fired power generation is becoming increasingly efficient, resulting in less coal being used per unit of electricity generated. Thermal efficiencies of coal-fired power plants have reached 40 percent, with the prospect of further improvement to 50 percent and better through the use of integrated gasification and combined cycle (IGCC) technology. Achieving this target would lead to a reduction in greenhouse gas (GHG) emissions of 10 to 20 percent compared to the best conventional plants today.

Extensive research is being undertaken to develop ultra-low emissions technology. While such technology is not yet commercial, it may be a viable option in the longer term. One major new technology stream is the gasification of coal in IGCC systems. Already, some 4,450 megawatts (MW) of electricity generating capacity of this plant type have come on stream worldwide at 17 locations.[126] Near-zero emissions are possible if such systems are combined with carbon capture and storage technologies. Numerous governments, including the US federal government, have initiated research and work programs to improve understanding of large-scale carbon capture and sequestration, with the aim of lowering costs. Already, the technology to store CO_2 in underground depleted oil and gas reservoirs is proven through commercial applications involving enhanced oil recovery.

6.2.6 Hydroelectricity

North America is a world leader in the production of hydroelectricity, with the EIA reporting a total of 157 gigawatts of installed hydro power as of January 2004.[127] Canada has the largest percentage of its electricity generation mix from hydro, at 59 percent, followed by Mexico and the US at 19 percent and 8 percent, respectively.

In Canada, the majority of hydroelectricity is produced in the five provinces of Quebec, British Columbia, Newfoundland and Labrador, Ontario, and Manitoba (see Figure 6.8). The La Grande complex in Quebec is the largest hydroelectric development in the world, with a capacity of over 15,000 megawatts (MW).

[126] Process Energy Solutions, 2005, accessed at www.processenergys.com/education-status.html

[127] Energy Information Administration, *International Energy Annual 2004,* Washington, D.C., Table 6.4.

Canada is expected to expand its hydroelectricity capacity with several projects under consideration in Quebec, the Northwest Territories, and Newfoundland. There are also several potential development sites in Manitoba. Environmental concerns, however, place a significant constraint on the potential for further hydro development.

Most of the potential hydroelectricity sites in the United States have already been developed, and due to regulatory restrictions hydroelectric generation is not forecasted to increase.[128] Mexico has added new hydro capacity with the El Cajón 750 MW hydroelectric project on Mexico's west coast, commissioned in March, 2007.

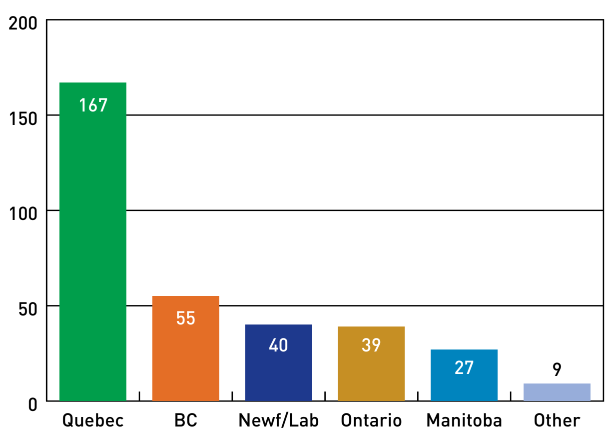
6.2.7 Nuclear

Nuclear energy is an important component of Canada's electricity generating fuel mix. Nuclear accounted for close to 15 percent of total generation in Canada in 2005.[129] Some provinces do not rely on nuclear generation at all while others, such as Ontario, use nuclear fuel for more than half of their generation (Statistics Canada, 2005).[130] Nuclear generation is also important in the United States, where its share of generation was about 19 percent in 2005.[131] The share of generation from nuclear fuel varies by state. Some states have no nuclear generation and others, such as New Hampshire, derive 42 percent of their electricity generation from nuclear fuel. The share of nuclear in Mexico's electricity generation was less than 5 percent in 2005.[132]

Most of the potential hydroelectricity sites in the United States have already been developed, and due to regulatory restrictions hydroelectric generation is not forecasted to increase.

Canada is the world's largest producer of uranium, accounting for almost 30 percent of annual world production. The economic benefit from mining and production of uranium was approximately $583 million in 2001.[133] The value of electricity produced by nuclear energy was estimated to be between $2.7 and $3.7 billion in 2001 (Statistics Canada), of which close to $200 million was exported. Total export revenues from electricity, uranium, reactor fuel, isotopes, heavy water, and Atomic Energy of Canada Limited services were close to $1.2 billion during the early part of the 2000s. Employment generated in positions directly related to the nuclear industry was over 20,000 in 2002.

Figure 6.8
Hydroelectric Generation in Canada, 2004 (terawatt-hours)



SOURCE: Statistics Canada 57-202

[128] *Ibid.*

[129] International Energy Agency, *Electricity Information 2007*, Paris, France, 2007.

[130] A March 18, 2004, report from the Ontario Power Generation Review Committee identified nuclear energy, through the use of refurbishment and new capacity, as part of the solution to Ontario's looming supply crunch. The Ontario Power Authority's December 2005 *Supply Mix Recommendations and Advice Report* proposed that nuclear should continue to enjoy roughly a 50 percent share of Ontario's electricity generation and installed capacity. This recommendation was accepted by the Government of Ontario.

[131] International Energy Agency, *Electricity Information 2007*, Paris, France, 2007.

[132] *Ibid.*

[133] *Economic Impact of the Nuclear Industry in Canada*, CERI, 2003, accessed at www.cna.ca/files/study/CNAStudySept16-03.pdf

7 WILL ENERGY EFFICIENCY
Improvements Alter the Balance?

The energy crisis of the 1970s triggered policy initiatives that included measures related to energy conservation and alternative energy sources. Legislation in the US supported research and development, training, and subsidies for qualified facilities, such as small power plants, that use renewables.[134] However, the main response at that time was to enhance options to supply the needed energy.

[134] For example, the 1976 *Public Utility Regulatory Policy Act* (PURPA).

Conservation and energy efficiency are once again gaining prominence. This time, the catalysts include higher and more volatile energy prices, constraints on new supply, and large infrastructure bottlenecks such as those that caused electricity blackouts in California in 2001 and in Ontario and the US Northeast in the summer of 2003. Moreover, an increasing concern with environmental integrity has provided support for the demand-side approach.

It is possible to distinguish between conservation and energy efficiency as follows:

- **Conservation:** a demand response to address energy shortages by altering normal activities; however, institutional, economic, and social barriers may delay or inhibit the realization of the energy saving potential from conservation.[135]
- **Energy efficiency:** a continuation of normal activity, relying on technology to increase efficiency, thereby reducing demand, while producing the same output (e.g. efficient lighting).

In the above definitions, energy efficiency refers to technical efficiency. It is also commonly used interchangeably with conservation to more broadly refer to all changes that result in decreasing the amount of energy used to produce one unit of economic activity, including technological, behavioural, and economic

[135] Conservation is also commonly used in discussions of supply, for example, ensuring optimal recovery from hydrocarbon reservoirs. However, in this study, we refer mainly to demand-side applications.

changes. For the purpose of this discussion, we use the term "energy efficiency" to broadly refer to both efficiency and conservation issues.

7.1 Investing in Energy Efficiency

The impacts of energy efficiency improvements on demand are based on several assumptions regarding equipment costs, rate of market penetration, consumer uptake, and potential policy measures. Reducing energy consumption, or choosing energy-efficient equipment that reduces the cost of energy, contributes to the competitiveness of companies, strengthens the economy, and benefits the environment. *Investment*, *market structure* and *environmental policies* influence the role of energy efficiency.

The benefits that improvements in energy efficiency can bring to the environment and the economy are difficult to measure. Benefits from efficiency must be quantified to determine how much is available, and at what cost, from competing schemes (and also in comparison with increasing supply). Consequently, the evaluation of energy efficiency programs still remains an important issue. While the process of assessing the cost effectiveness of an energy efficiency improvement is a standard exercise in project evaluation, the difficulties in measuring the benefits of improved efficiency complicate the analysis.

7.2 Electricity: Energy Efficiency and Demand-Side Management

In many electricity markets, the requirements for generation and transmission are determined by peak demands. If consumers can be persuaded to consume less during peak times, some generation and transmission investments may not be required. Mechanisms to do this are sometimes described as demand-side or demand response mechanisms.

Early demand-side programs tended to focus on energy efficiency (including information programs, rebates, and installation of energy-efficient devices) and incentives for off-peak usage (time-of-use rates) or lower rates for interruptible service. The perceived success of demand-side programs in the 1990s was mixed, at least partially due to the difficulty in verifying the cost and benefits associated with particular programs. A major barrier to achieving greater demand response has been the limited exposure many customers have to prices that vary over time and thus prices that are able to reflect the scarcity of supply.

More recent attention on the demand side in electricity has focused on real-time pricing and demand-side bidding. In some markets these have been successfully employed for larger customers. Other options include direct control programs, whereby equipment such as air conditioners can be switched off (or cycled) during times of peak demand. Some regulatory issues remain to be resolved in the deployment of new metering, monitoring, and control technologies.

The potential benefits of energy efficiency programs in electricity are quite large. Estimates by the American Council for an Energy Efficient Economy indicate energy efficiency savings in the US "could negate about 40 percent of the growth in peak demand predicted over the next decade."[136]

Economists have questioned whether technical change that lowers the amount of energy required per unit of output for energy-intensive applications actually results in lower energy consumption. The Khazoom-Brookes Postulate which Daniel Khazoom and Leonard Brookes ascribe to Stanley Jevons,[137] argues, "it is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth." To illustrate this point, Jevons goes on to state, "The reduction of the consumption of coal, per ton of iron, to less than one third of its former amount, was followed, in Scotland, by a ten fold increase in total consumption, between the years 1830 and 1863, not to speak of the indirect effect of cheap iron in accelerating other coal-consuming branches of industry." In a more modern example, Brookes and Khazoom note that the introduction of wide bodied aircraft had been forecast to reduce the number of flights, but the increase

136 S. Nadel, F. Gordon, and C. Neme, *Using Targeted Energy Efficiency Programs to Reduce Peak Electrical Demand and Address Electric System Reliability Problems*, American Council for an Energy Efficient Economy, 2002.

137 S. Jevons, *The Coal Question*, 1865.

in air travel due to the lower cost per seat-mile raised productivity per aircraft and resulted in an increase in the number of flights.

The essence of the Khazoom-Brookes Postulate is that an improvement in energy efficiency associated with a particular output, other things being equal, acts like a decrease in energy prices, causing a lowering of the price of the output and a rise in quantity demanded. This phenomenon has also been labelled “snapback” and “rebound”. Advocates of the Khazoom-Brookes Postulate may go on to argue that the way to achieve genuine reductions in energy consumption is to put a “tax wedge” between energy production and consumption to ensure that higher energy prices serve the purpose of reducing energy demand without stimulating energy supply. Others insist that energy efficiency measures are the cheapest and fastest way to lower energy consumption and greenhouse gas emissions.

7.3 Role of Energy Efficiency in Meeting Environmental Targets

Increasing energy efficiency, provided that measures to prevent a Khazoom-Brookes type of demand rebound are in place, has the potential to reduce energy shortages, lower reliance on energy imports, mitigate the impact of high energy prices, reduce pollution, promote investment in new technologies, and lower energy intensity. The combination of these effects may also be beneficial to general economic performance. Improvements in energy efficiency, with suitable policies in place, can weaken the link between economic growth and energy demand, delaying the need for new capacity. Conservation also has a role to play in providing a near-term solution to the supply-demand imbalance, dampening prices and the impact of any supply shortfall.

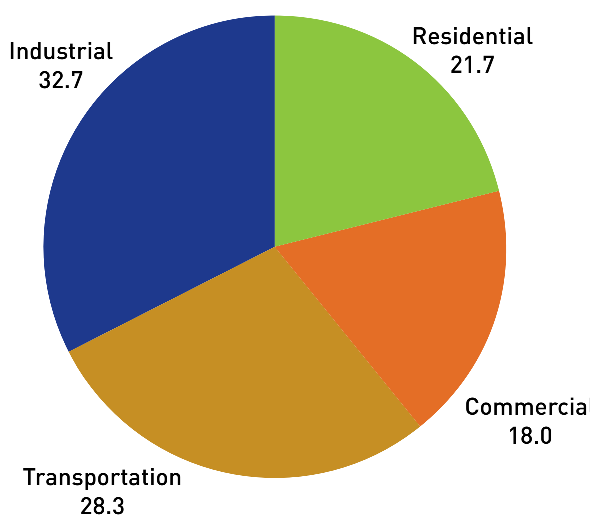
Although energy efficiency and conservation are perceived as essential elements in environmental and energy policy goals, there is wide disagreement on what the targets should be and how to achieve them. In the 1970s, energy policies were aimed at providing sufficient energy for economic growth and ensuring energy security. In the 1980s and 1990s, partly driven by cross-boundary issues relating to acid rain and climate change, energy policies began to consider energy efficiency as a means of both meeting energy needs and addressing global environmental concerns. The dual role of energy policy has made both implementation and measurement more complex.

To achieve the existing emission targets set out in agreements such as Kyoto, energy policies in North America are addressing the efficiency with which fuels and electricity are used. This is clearly outlined in the Bush Administration’s US energy policy. Policy measures targeting the supply side in the US consist of technology development programs and fiscal measures such as emission taxes. Policies targeted at demand-side energy efficiency include energy performance standards, technology procurement programs, and utility demand-side management.

7.3.1 Efficient Personal Energy Use

The residential sector is a major contributor to North America’s energy consumption. In 2006, the residential sector accounted for over 21 percent of energy consumed in the United States, as illustrated in Figure 7.1. The majority of residential energy consumed in the United States was for space heating.

Figure 7.1
US Total Energy (Primary and Other) Consumption by End-use Sector, 2006 (percent)



SOURCE: US Energy Information Administration, accessed at http://tonto.eia.doe.gov/merquery/mer_data.asp?table=T02.01 in September 2007.

Individuals and families produce 13 percent of Canada's GHG emissions in their homes just from day-to-day activities.[138] Consequently, improving the efficiency with which energy is used in homes could make a significant contribution to achieving current energy policy goals.

Standards and labels have proven successful policy tools for increasing end-use efficiency by accelerating the infiltration of energy-efficient technology into the marketplace. Standards function to drive manufacturers to produce more efficient models. Labels function to educate consumers as to the benefits of purchasing energy-efficient models.

An example of a successful labelling program is the ENERGY STAR labelling program, which the US, Canada and Mexico have recently agreed to expand as part of NAFTA harmonization of standards. The ENERGY STAR label identifies energy-using products that meet specified efficiency criteria. The label also provides a basis for publicity campaigns, supports purchasing programs, and helps market energy-efficient models.

Even when choices of energy-efficient products are economically justifiable (the increased initial cost is outweighed by the reduction in the cost of energy consumption), consumers may be unwilling or unable to make the required investment. Uncertainty about future energy prices may make the benefits of energy-efficient products difficult to estimate. Budget constraints may also lead to a preference for products with a low initial cost. Other consumers may require that the savings be sufficient to return the money expended over a period of time as short as one to two years.[139]

Improvements in the energy efficiency of appliances usually occur in combination with increased numbers and/or larger appliances. For example, the electricity consumption of a new refrigerator in Canada in 2004 was only half of the corresponding figure for 1990, despite an increase in refrigerator size.[140] Such offsetting effects complicate the measurement of potential benefits of energy efficiency programs.

Other common residential programs include:

- **Education/information:** improved information for customers on reducing consumption. This could also take the form of an energy audit.
- **Grants/rebates to encourage efficient energy use:** for example, providing a subsidy for additional insulation, the replacement of aging gas furnaces, or for domestic generation (e.g. solar panels for water heating).

The residential sector is a major contributor to North America's energy consumption. In 2006, the residential sector accounted for over 21 percent of energy consumed in the United States.

7.3.2 Efficient Energy Use in Industry

One method of measuring energy efficiency is via energy intensity, defined as the amount of energy it takes to produce one dollar of gross domestic product. Canada has the highest energy intensity of the three NAFTA countries, as shown in Figure 7.2. The high Canadian energy intensity is in part related to the development of Canada's rich resource base and its role as an exporter of primary energy. For the last several years, North America's energy intensity has been slowly declining, a trend that is expected to continue through

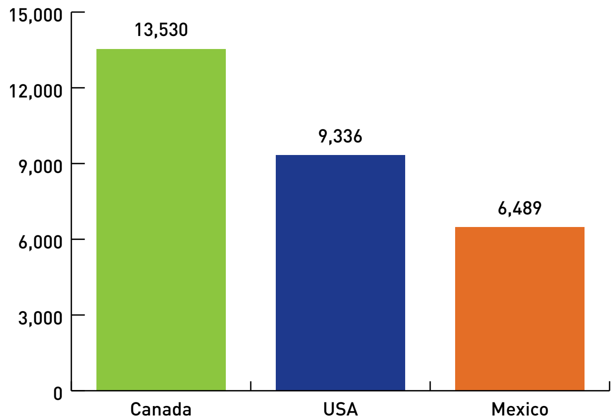
[138] Calculated as residential greenhouse gas emissions plus a residential pro rata share of "electricity and heat generation" greenhouse gas emissions, expressed as a percentage of national energy-related greenhouse gas emissions per Canada's Greenhouse Gas Emission Tables, 1990-2004, accessed at www.ec.gc.ca/pdb/ghg/inventory_report/2004_report/ta8_2_e.cfm

[139] In some cases this is rational. For example, a high-efficiency furnace that requires five years to recover its increased capital cost through operating savings might not be chosen by a family considering moving in the next year or two. In other cases, the choice simply reflects incomplete understanding of the benefit-cost relationships involved.

[140] Natural Resources Canada, *Energy Consumption of Major Household Appliances Shipped in Canada — Trends for 1990-2004*, December 2006, Ottawa, Ontario, database accessed at www.oee.rncan.gc.ca/corporate/statistics/neud/dpa/trends_res_ca.cfm

Figure 7.2

North American Energy Intensity by Country, 2004 (Btus per (2000) US dollars)



SOURCE: US Energy Information Administration, International Energy Annual*, accessed at www.eia.doe.gov/emeu/international/energyconsumption.html (Table E.1p).*

2025.[141] The largest portion of the decline in energy intensity is attributable to energy efficiency improvements; the remainder is due to structural changes and fuel switching.

Natural Resources Canada (NRCan) has invested heavily in the promotion of energy efficiency and renewable energy programs to help address climate change. The majority of funds is invested in energy efficiency programs (leadership, information, voluntary actions, regulation, and research and development). In 1991, NRCan initiated a comprehensive Efficiency and Alternative Energy Program targeting residential, commercial, industrial, and transportation end-use sectors. Some initiatives include:

- Development of a comprehensive combustion and environmental emissions research facility in Ottawa.
- Development of standards under the *Energy Efficiency Act.*
- The C-2000 Program for commercial buildings, which supports state-of-the-art building construction. The first building completed under this program uses 50 percent less operating energy and 28 percent less water than a conventional building.
- The Federal Buildings Initiative (FBI) and Energy Innovators Initiative (EII) provide organizations with a full package of products and services to help plan, finance, and implement comprehensive energy efficiency improvements. The package includes how-to guides, technical fact sheets, a list of qualified energy service companies, and project financing options.
- NRCan and the National Research Council developed Canada's first comprehensive energy efficiency codes (the Model National Energy Code for Buildings and Houses) to establish acceptable levels of energy efficiency.

One of the most successful programs for achieving energy efficiency in Canadian industry is the Canadian Industry Program for Energy Conservation (CIPEC). CIPEC is a government-industry partnership that provides services to help Canada's industrial sectors develop energy efficiency goals and action plans. CIPEC is a network of 43 trade associations that represent more than 5,000 companies and more than 98 percent of secondary industrial energy demand in Canada. Over the period 1990–2004, CIPEC reports that its members have reduced their combined energy intensity by 9.1 percent, equivalent to 0.7 percent per year.

Efficient Energy Use in the Transportation Sector

The internal combustion engine (ICE), with its reliance on petroleum-based fuels, is expected to maintain its dominant position in the transportation sector. Continuing advancements in ICE design, coupled with onboard engine management systems, are expected to result in some improvements in fuel efficiency and emissions control.

The possibility of more widespread use of gasoline-electric and diesel-electric hybrid vehicles could yield a 15 to 20 percent reduction in liquid fuel consumption on a per kilometre or a per mile basis. (The reader is cautioned that reduced energy intensity may result in increased use, as explained above, and therefore the apparent energy saving may be reduced or eliminated.) Although hybrid vehicles have been on the market for a decade, sales have been low. Barriers to increasing

[141] Energy Information Administration, *International Energy Outlook 2007*, Washington, D.C., May 2007.

sales include higher initial price and the perception of inferior performance (as measured along dimensions other than fuel efficiency and emission rates). However, more automobile manufacturers, including the "Big Three" in North America (GM, Ford, and Chrysler LLC), have entered the hybrid market.

The possibility of more widespread use of gasoline-electric and diesel-electric hybrid vehicles could yield a 15 to 20 percent reduction in liquid fuel consumption on a per kilometre or a per mile basis.

Battery-powered electric vehicles (EVs) offer the possibility of quiet and pollution-free operation. They are also currently the only vehicles to meet California's Zero Emission Vehicle requirement. However, there may be emissions "upstream," depending on the fuel that is used to generate electricity. EVs continue to face issues with respect to range and recharging convenience. Although recent advances in battery and electric motor technologies have made EVs more practical, they are not expected to be a major player unless significant improvements are made to battery technologies that provide higher energy densities at lower costs.

Fuel cell vehicles (FCVs) have the potential to revolutionize on-road transportation, but are not expected to reach the mass market until late in the next decade. While EVs use electricity from an external source (and store it in a battery), FCVs create their own electricity. Onboard fuel cells create electricity through a chemical process using hydrogen fuel and oxygen from the air. FCVs can be fuelled with pure hydrogen stored onboard in high-pressure tanks or in the form of metallic hydrides, or they can be fuelled with hydrogen-rich fuels, such as methanol, natural gas, or even gasoline; but these fuels must first be converted into hydrogen gas by onboard reforming.

8 THE SPECIAL CASE
of North American Electricity

The participants in the electricity industry consist of Provincial Crown Corporations in Canada, utilities throughout North America owned by private investors and municipalities, generation by manufacturers largely for their own use, and independent power producers. After almost 100 years of regulated electricity supply, deregulation and restructuring of the electricity industry, including the introduction of markets, are still fairly new phenomena. Soon after the first electric companies started to operate, during the last decade of the 19th century, aggressive competition gave way to the geographic division of the electricity market into regional monopolies and the absence of any competition.

Until the latter part of the 20th century, the traditional structure of electricity markets was a *vertically integrated monopoly* responsible for generation, transmission, and distribution. Under this structure, customers had no choice about the supplier of power. Consumers were compensated for the lack of choice by regulated promotional electricity tariffs, in the form of declining block rates, and by decreasing average bills due to ever-decreasing costs associated with economies of scale.

The first practical steps to reintroduce some measure of consumer choice and competition took place in the early 1970s, following more frequent requests by regulated electric utilities for rate increases. Economies of scale seemed to come close to being exhausted, and misadventure led to a few bankruptcies. The energy crisis of the 1970s prompted legislation that introduced non-traditional electricity generators, in the form of subsidized qualified facilities, and marginal cost based rates. The rates and alternative sources of electricity made consumer choice a possibility.

The last decade has seen a major change in the North American electrical industry. Many areas have restructured,[142] allowing a shift of ownership in assets from public to private hands. In the US, the share of installed capacity provided by competitive suppliers has increased from about 10 percent in 1997 to about 35 percent in 2003.[143] Present trends indicate that this industry will be significantly restructured over the next decade.[144] Most in the industry have adopted a functional separation of activities into different companies (usually in generation, transmission, and distribution). In many markets, restructuring has involved the establishment of wholesale competitive markets (known as "power pools"). Some markets have continued restructuring, allowing customers to purchase supplies from competitive retailers.

Despite the rapid pace of electricity restructuring, it remains a central energy issue. Not all restructuring has proven successful, as evidenced by the high-profile problems experienced in California and Ontario in recent years. Problems with restructuring have caused some states and provinces to postpone plans (in some cases, indefinitely). Where restructuring has successfully avoided the problems experienced in California and Ontario, some uncertainty remains with respect to the "best" market design.

[142] Electricity market restructuring emphasized the potential of competition in generation and retail services, along with operation of transmission and distribution as a monopoly.

[143] United States Department of Energy, Office of Electric Transmission and Distribution, *Grid 2030 — A National Vision for Electricity's Second 100 Years,* Washington, D.C., July 2003.

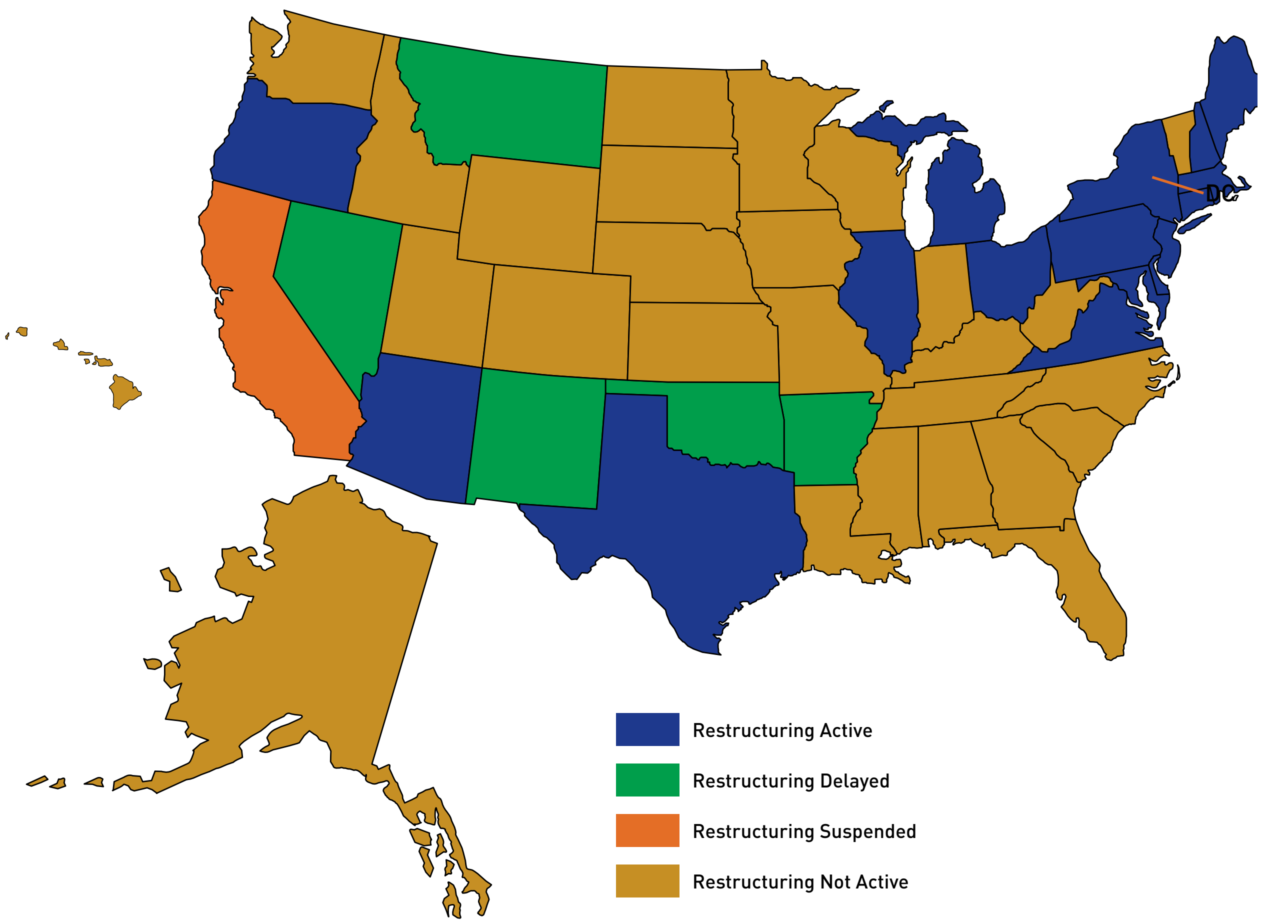
[144] G. Edwards and R. Edwards, *Electricity Generation in Canada: Tax Depreciation Issues Arising from Market Deregulation and Climate Change*, Study No. 87, Canadian Energy Research Institute, Calgary, Alberta, 1999, p. 11.

For those provinces and states that have not restructured, as far as establishing competitive wholesale markets, the main issue remains whether this move would be desirable. If a traditional monopoly structure is maintained, problems that attend monopoly power need to be dealt with: How should potential problems of overcapitalization be handled? How should lack of market signals to indicate the need for new investment be overcome? A summary of electricity market restructuring in the US is given in Figure 8.1.

A summary of electricity market restructuring in Canada is given in Figure 8.2. In this figure, "Functional Separation" refers to partition ownership and activities of generation, transmission and distribution. "Wholesale Open Access," i.e. transmission, is offered equally to all interested parties and generators or marketing agents compete to sell their power to power pool (wholesale competition). Retail competition allows generators or retailers to sell electricity directly to customers.

In Canada, wholesale competition has been introduced in all provinces with the exception of Newfoundland and Labrador, PEI and the Territories. Full retail competition has been introduced in the provinces of Alberta and Ontario.

Figure 8.1
Status of Electricity Restructuring in the United States, February 2003



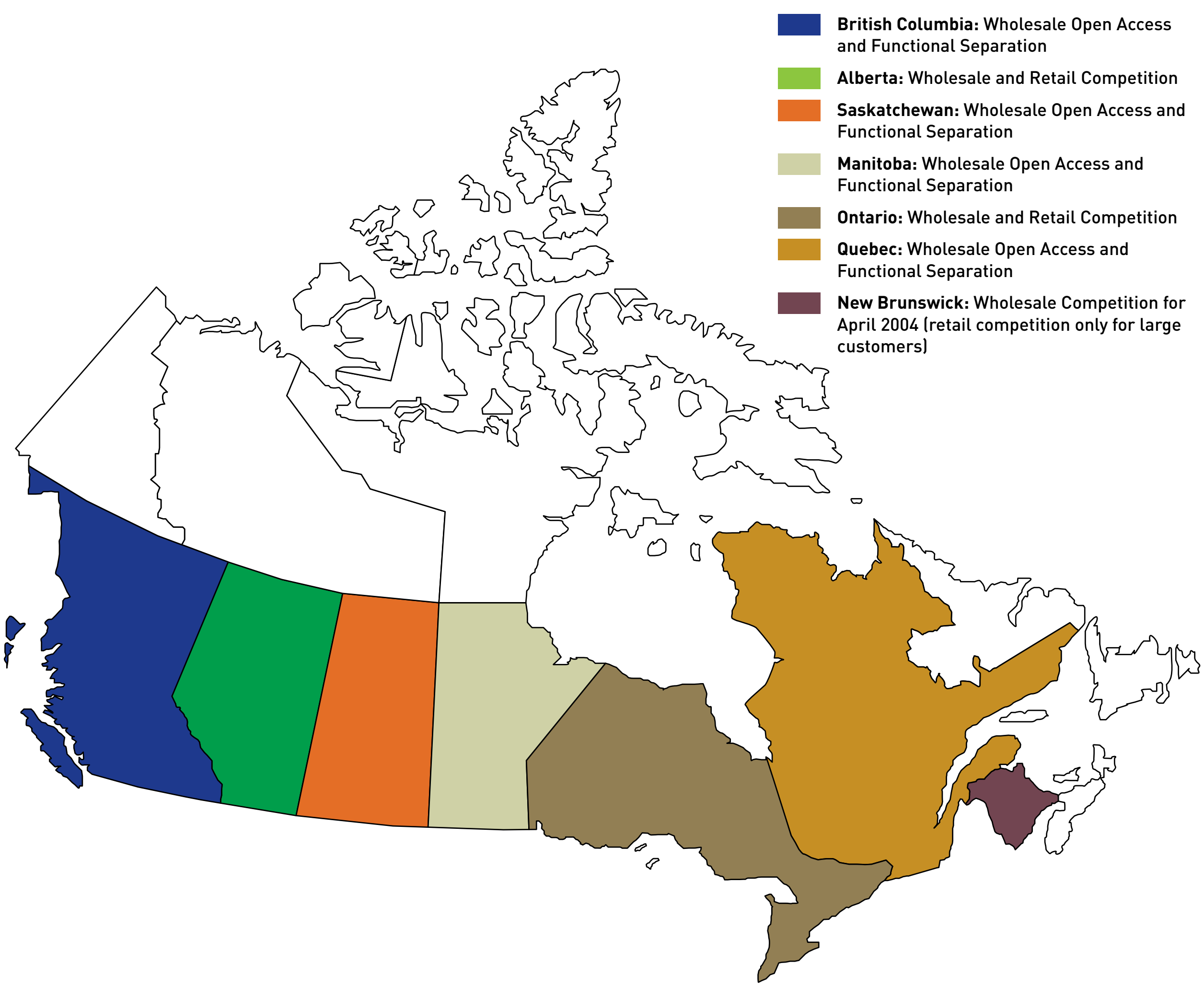
SOURCE: US Energy Information Administration, accessed at www.eia.doe.gov/cneaf/electricity/chg_str/restructure.pdf

Some of the main issues in electricity restructuring include:

- How to ensure that *reliability* of the system is maintained?
- Is *price volatility* a problem?
- How to deal with abuses of *market power*?
- Are there benefits from *full retail competition*?
- Should restructuring markets adopt a *standard market design*?
- What are the options for markets not adopting a competitive wholesale market?

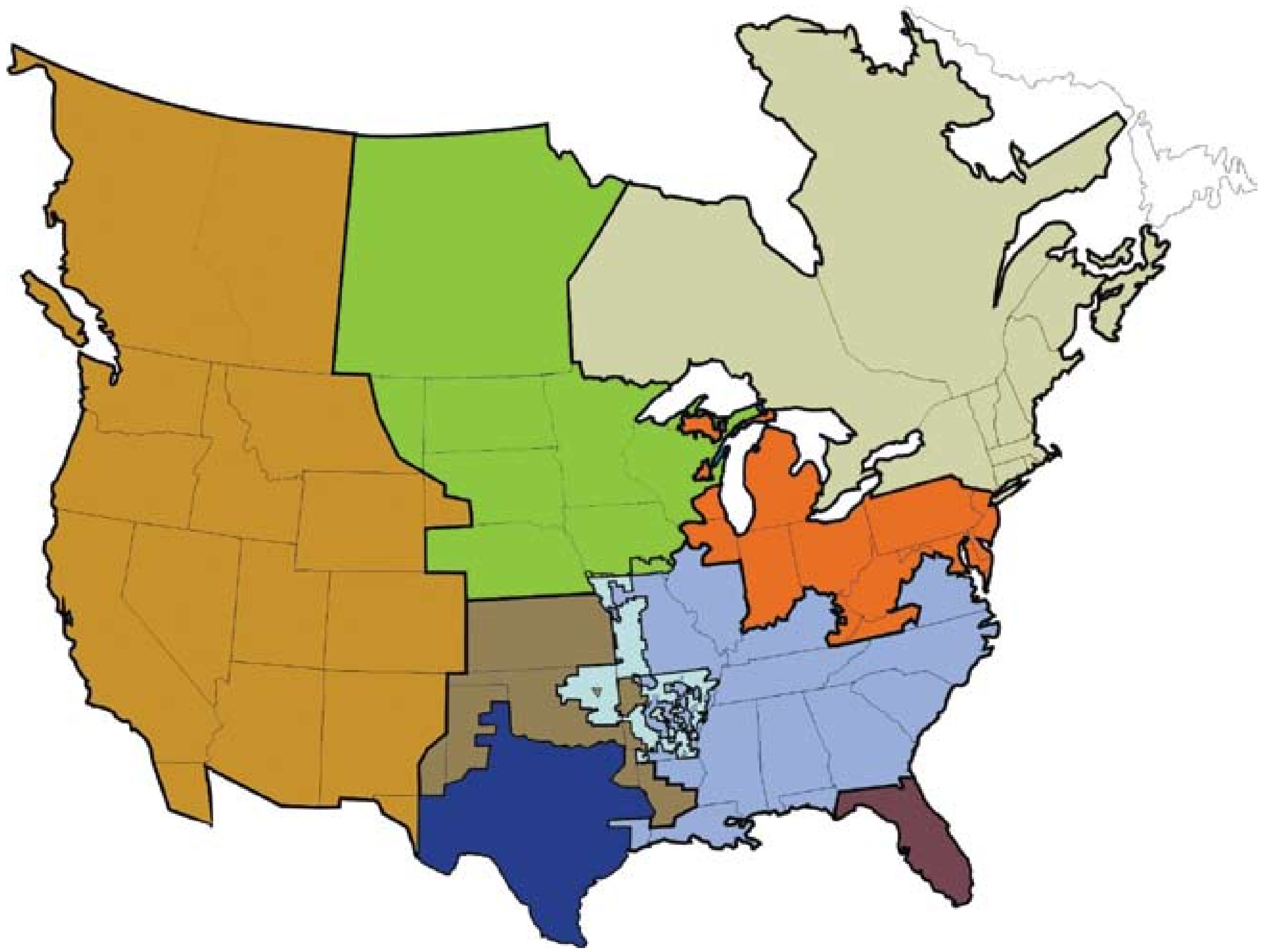
Reliability is a critical characteristic of modern electric systems. Two functional aspects of reliability are "adequacy" and "security" of the grid. Adequacy is the ability of the electric system to supply the aggregate electrical demand at all times. Security is the ability of the electric system to withstand sudden disturbances.

Figure 8.2
Status of Electricity Restructuring in Canada, 2003



SOURCE: Based on Cross-Country Electricity Snapshot Reliability, Natural Resources Canada.

Figure 8.3
North American Electric Reliability Council



Source: www.nerc.com/regional/

System reliability issues came to the fore in reaction to the 1967 Northeast Blackout in an effort to promote reliability in the electric utility systems of North America. There is an obvious cost associated with the disruptions (blackouts). It is also obvious that investment in system reliability will affect the cost of electricity.

Figure 8.3 is a map of the North American Electric Reliability Council (NERC) jurisdiction area which encompasses essentially all the power regions of the contiguous United States, adjoining Canadian provinces and a small portion of Mexico.[145] NERC consists of eight regional councils[146] and under proposed legislation, may be granted mandatory powers for enforcing reliability standards.

[145] Outside NERC regions, between the US and Mexico there are some problems in ensuring the compatibility between interconnections.

[146] NERC consists of Western Electricity Coordinating Council (WECC), Midwest Reliability Organization (MRO), Southwest Power Pool (SPP), Electric Reliability Council of Texas (ERCOT), Reliability First Corporation (RFC), Southeast Electric Reliability Council (SERC), Northeast Power Coordinating Council (NPCC), and Florida Reliability Coordinating Council (FRCC).

Reliability can be thought of in terms of two components, short-term *security* (the ability of the electric system to withstand unexpected events) and long-term *adequacy* (the ability of the electric system to meet expected demand). Security and adequacy can also be thought of as relating either to generating capacity or to the transmission network.

Generation

In the move to competitive markets, private investors typically fund new generation. In nearly all markets there is concern over whether restructured markets provide adequate signals of when new generation may be needed. These concerns include:

- Does uncertainty over future regulation deter investment?
- Do price caps prevent prices from adequately reflecting scarcity?

The need for new generating capacity is causing particular concern in Ontario. This is in part due to retirement of existing generation, as well as demand growth. Ontario Power Authority (OPA) estimated that the demand will begin to exceed supply by year 2014. Coal-fired stations are scheduled to be retired by that year, and loss of nuclear capacity will begin in 2013. OPA estimated that the gap between supply and demand (with declining supply and increasing demand) will reach about 24,000 megawatts (MW) by 2025 without new generation.

In 2005, to avoid future supply and demand imbalances[147] OPA reviewed Ontario's supply options and made recommendations to the government on the future supply mix: maintaining the share of nuclear generation, and replacing coal by raising the share of gas-fired generation and renewable resources. Ontario generation capacity is expected to increase from 30,662 MW in 2005 to 41,750 MW in 2025.

[147] OPA, "Supply Mix Advice and Recommendations," 2005, accessed at www.powerauthority.on.ca/Report_Static/157.htm

In the move to competitive markets, private investors typically fund new generation.

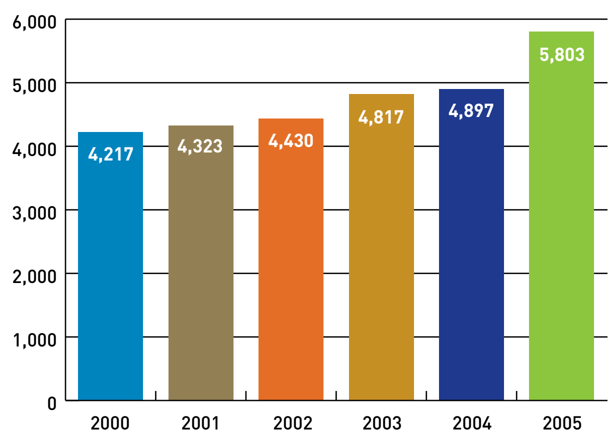
Transmission

The North American electricity transmission system consists of about 204,000 miles of high-voltage lines (158,000 miles located in the US). Much of this system is now aging, and a number of bottlenecks are causing problems for reliability and increased electricity trade.[148]

From 2000 to 2005, the US electric companies invested more than $28 billion in the nation's transmission system[149] (Figure 8.4).

A major obstacle to new transmission in North America is obtaining planning and approval. Reasons for this include multiple layers of government review, public opposition to new lines, and cross-jurisdictional issues (transmission lines may have an impact on more than one province or state). Transmission planning can

Figure 8.4
US Transmission Investment by Electric Companies (millions of 2005 dollars)



SOURCE: Edison Electric Institute, 2006.

[148] For further discussion on transmission issues in North America, see R.W. Gale and M. O'Driscoll, *The Case for New Electricity Transmission and Siting New Transmission Lines,* Edison Electric Institute, Washington, D.C., 2001.

[149] Edison Electric Institute, accessed at www.eei.org/industry_issues/energy_infrastructure/transmission/index.htm

also lead to environmental concerns over land use and the impact of electrical and magnetic fields. Careful transmission planning can alleviate some problems of local air quality by allowing siting of new generation away from population centres or other sensitive areas.

Even in restructured markets, transmission remains under monopoly provision. A key issue is to resolve how new transmission is best planned, regulated, and funded. A related question is how congestion on the transmission network should be reflected in prices.

NERC projects 7,100 miles of transmission lines expansion (230 kV or greater) in various NERC regions for the period 2004 to 2013.[150]

8.1 Price Volatility

Under the traditional regulated structure, prices for almost all customers were fixed for long periods of time. This situation provided some certainty for consumers, but prices did not reflect scarcity (i.e. prices were not high when capacity was limited) and therefore did not encourage consumers to conserve. With the advent of competitive electricity markets, the price of energy is able to reflect its scarcity (prices are high when capacity is in short supply, and low in situations of excess capacity). Such a situation encourages efficient use of energy (conservation), and also indicates whether new resources are needed (high prices can be seen as a signal to investors that profitable opportunities exist). Figure 8.5 shows the 2006 average electricity prices for the residential customers who consumed about 1,000 kWh of electricity per month in 21 North American cities.

However, there may also be concerns that high prices do not reflect genuine scarcity, but are caused by problems in the market design — enabling abuse of market power (see Section 8.2). Fluctuating prices, whatever the cause, may be inconsistent with customers' and politicians' expectations, should they view electricity provision as a "right." In some markets this has resulted in political intervention and great uncertainty over the future of restructuring.

Some jurisdictions in Canada have enacted "heritage contracts" in order to shield residents from variations in the wholesale price for electricity. Hydro Québec Production is currently mandated to supply 165 TWh annually to the Quebec market through a heritage pool[151] at a price of $0.0279/kWh (hydroelectric resource endowment for the benefit of provincial citizens). Beyond the 165 TWh, it is free to sell power to Hydro Québec Distribution, or to other markets, at competitive market prices. The Heritage Pool rate can be reduced but not increased. Residential electricity rates in Quebec are currently the lowest in North America.

In British Columbia, under the 2002 Energy Plan, a legislated heritage contract was established for an initial term of 10 years to ensure BC Hydro customers benefit from its existing low-cost resources. BC Hydro's Energy Implementation Plan (April 2003) proposed a new rate for residential customers (under a heritage contract) and a stepped rate[152] for industrial customers. A British Columbia Utilities Commission report dated October 17, 2003, supported both these proposals and also recommended the consideration of time-of-use rates for industrial customers.[153]

[150] EEI, "Meeting US Transmission Needs" — July 2005, p. 23, accessed at www.eei.org/industry_issues/energy_infrastructure/transmission/meeting_trans_needs.pdf

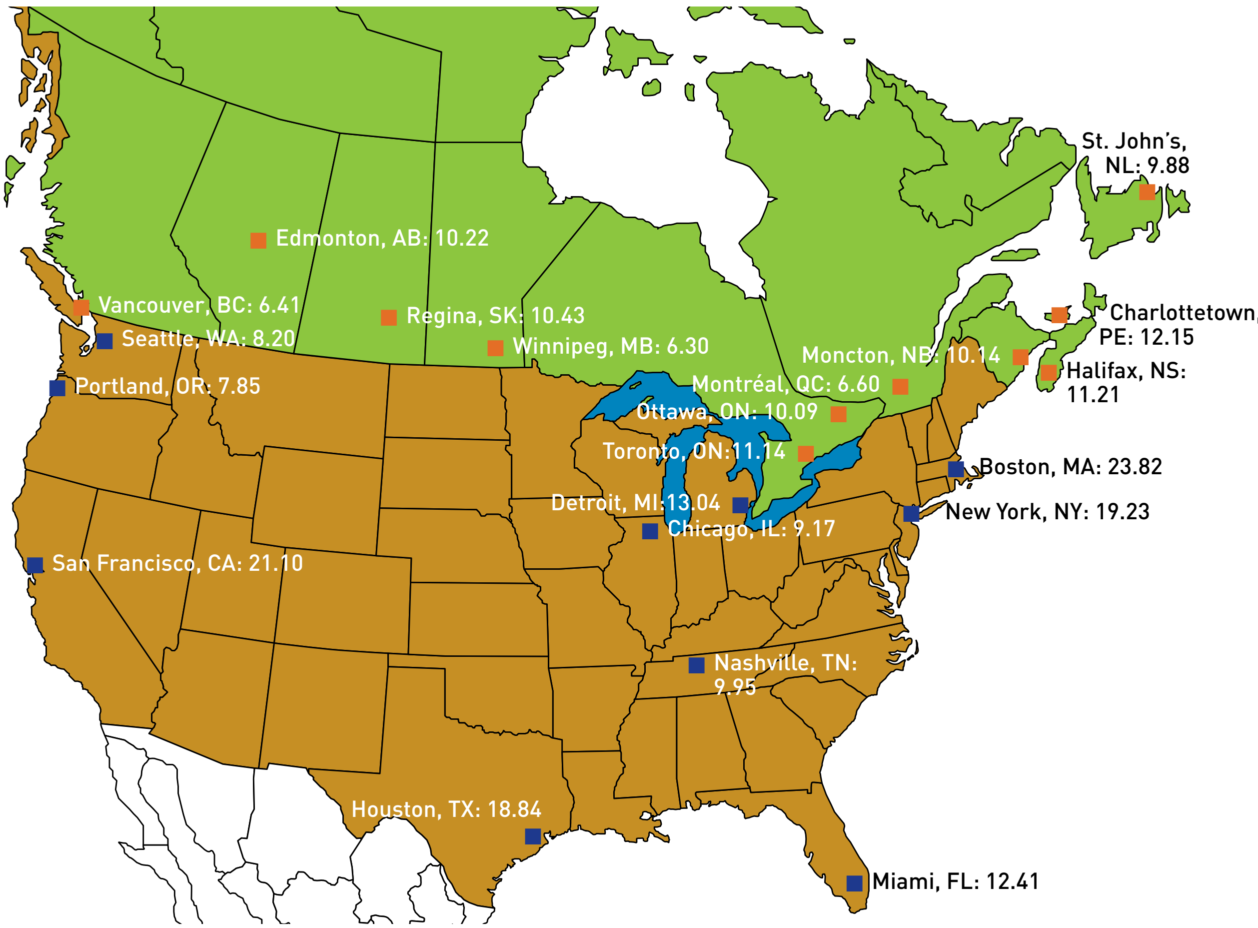
[151] Advice Concerning the Distribution of Electricity to Major Industrial Consumer in Quebec — June 2005, accessed at http://regie-energie.qc.ca/audiences/3563-05/A-2005-01_Sommaire_ENG_31mai2005.pdf

[152] Summary of BC Hydro's March 5 Workshop on Stepped Rates & Access Principles, accessed at www.bchydro.com/rx_files/policies/policies4725.pdf

[153] British Columbia Utilities Commission, British Columbia Hydro and Power Authority and an Inquiry into a Heritage Contract for British Columbia Hydro and Power Authority's Existing Generation Resources and Regarding Stepped Rates and Transmission Access, *Report and Recommendations*, October 17, 2003.)

Figure 8.5

Average Residential Electricity Prices for Major North American Cities on April 1, 2006 (Cdn¢/kWh)



SOURCE: *Hydro Québec,* Comparison of Electricity Prices in Major North American Cities, *2006.*

8.2 Market Power

In a deregulated market it may be possible for generators to exercise market power by physically withholding available capacity or raising the price at which capacity is made available. In order for this to be profitable, a withholding generator must still have sufficient capacity in the market such that the profit forgone from withholding is outweighed by the increased revenues of the capacity in service.

Allegations of abuse of market power may be difficult to prove. The reason for this could be that it is difficult to identify market power spikes (market power may be easiest to exercise when capacity is tight), or the threat of ex-post investigation and action by regulatory authorities has been sufficient to dissuade abuse of market power. Suspicions of market power abuse and gaming in contributing to the California electricity crisis led to Federal Energy Regulatory Commission (FERC) investigations and "show cause" orders (orders to submit specific information on actions during the crisis).[154] FERC's success in reaching settlements with some companies accused of gaming is seen by the FERC chairman "as a warning to all energy companies that attempts to manipulate energy markets will have consequences."[155]

It is also possible that capacity may not be made available to the market for reasons other than an abuse of market power. Some generator's plant may not be competitive at prevailing market prices, suggesting it be retired from baseload service. For other generators, the market design may not provide sufficient opportunity to offer power into the market. For example, if prices an hour or day ahead are not forecast with a reasonable degree of accuracy, some generators may be unable to respond in a timely manner, even though they would have been willing to make power available at the prevailing market price.

The scope for the abuse of market power is limited in many deregulated markets (including in Alberta and Ontario) by the presence of a wholesale price cap (a level above which prices are not allowed to rise). However, the presence of a price cap may have adverse effects on other parts of the market (including blunted incentives for the provision of new capacity). There may also be less intrusive ways of tackling market power (e.g. divestiture of assets to many generators).

8.3 Full Retail Competition

Full retail competition in electricity describes a further stage in the restructuring process.[156] Under such a system, all customers, from industrial to residential, can choose from whom they purchase electricity. The advantages of retail competition stem from increased customer choice. Customer choice may provide an incentive for distribution companies and retailers to offer a level of customer service better suited to customer needs. Increased customer choice among competing retailers is also a mechanism that may ensure that lower prices resulting from wholesale competition result in lower prices at the retail level. Consequently, the existence of a smooth-functioning competitive wholesale market and transparent spot prices are preconditions for retail customers to realize the potential benefits of competition. Retail competition is also as important in exposing all customers to price signals. If these price signals reflected the true cost of provision, they would promote an efficient level of conservation and efficient demand response; they would also provide efficient signals for new investment.

Retail competition among larger industrial users appears to have been relatively successful, with large numbers of retailers and choice for customers. Retail competition for smaller users (including residential customers) has been much more problematic. In many jurisdictions, including Alberta, the rate of "switching" (when customers leave an incumbent supplier for a competitive supplier) has been very low.[157] This reflects the fact that for smaller users, the savings are not large and not obvious. Individuals have to understand the market fairly well and then be able to identify benefits in order to decide to switch. This is a pervasive problem in opening up the retail market, although there has been some success in a few jurisdictions.

[154] Federal Energy Regulatory Commission, *Commission Issues Sweeping Show Cause Orders to Companies Alleged to Have Gamed Western Energy Markets*; *Hearings Set to Explain Actions, Address Remedies*, Press Release, June 25, 2003.

[155] Federal Energy Regulatory Commission, *FERC Approves Settlement with Reliant in California Cases; Proceeds Could Total $50 million*, Press Release, October 2, 2003.

[156] Prior to the introduction of full retail competition, many markets have adopted an intermediate step of allowing competition in the supply to large industrial customers.

[157] Switching rates have been higher in other jurisdictions (such as Texas) where regulated rate options have been set with some "headroom" to allow lower competitive offers to be attractive to customers. It is not clear whether such measures are sufficient to establish a vibrant competitive market.

8.4 Standard Market Design

Not all markets that have restructured have done so in a uniform way. This has created some problems for interconnected markets with different rules and some disagreement about the best design. The Federal Energy Regulatory Commission (FERC) has proposed a Standard Market Design (SMD) to overcome some of these problems. They propose an SMD to provide "rules and incentives for new investment, and to promote current stability and lower costs."[158]

SMD presents a framework for wholesale markets that is intended to address problems encountered in restructured markets (such as market power, capacity adequacy, and how to manage the cost congestion of transmission networks and provide a level playing field for load, generators, and technologies). Although the proposal for SMD in the US has not been enacted, regulatory moves toward standardization also have important implications for the structure of markets in Canada (and to a lesser extent Mexico).

8.5 Other Issues

Other issues faced by the electricity industry include:

- What is the extent to which increased energy efficiency and demand-side response represent an economic alternative to new generation capacity?
- Given high natural gas prices and concern over emissions, what will be the "fuel of choice" in constructing new electric generation?
- Even in restructured markets, transmission remains under monopoly provision. How should transmission best be planned, regulated, and funded?

These and other aspects of electricity supply, demand, and market structure are the subject of review in most countries of the world. The restructuring of markets in many regions to allow competition in some areas of the electricity business has revealed both problems and opportunities that require greater understanding. Across the world, these issues have been addressed in different ways and each country has an opportunity to learn from others today and to adapt those lessons to its own needs, thus providing another experiment that may benefit others in future.

[158] Federal Energy Regulatory Commission, SMD Questions and Answers, accessed at www.ferc.gov/industries/electric/indus-act/smd/nopr/q-a.pdf on March 17, 2004.

APPENDIX A The Oil Refining Sector in North America, 1970–2006

Crude oil is converted into consumer products — such as gasoline and jet fuel — through processing at refineries, where crude oil streams are distilled and fractionated, the oil molecules are cracked, and impurities removed. This section analyzes the developments of the oil refining sector in North America, comprising the US, Canada and Mexico during the period 1970–2006.

A.1 Country Shares in Refining and Consumption

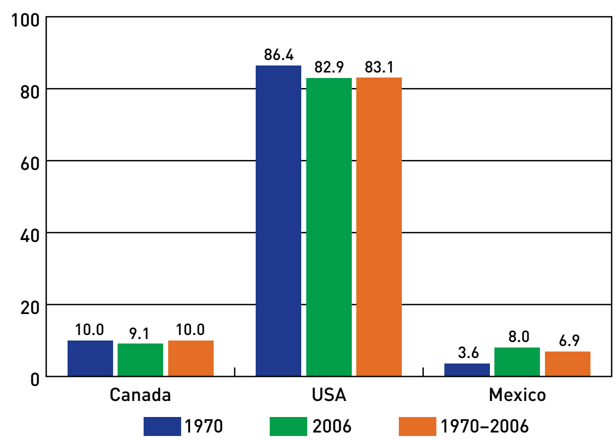
Total capacity of operating refineries in North America grew from 13.9 million barrels per day in 1970 to its all time high, mostly due to the US government support, of 22.2 million barrels per day in 1982, but gradually moderated to 20.9 million barrels per day in 2006. A detailed analysis of the developments in the US refinery sector in subsequent sections will shed more light on this.

Over the period 1970–2006 an average of 83.1 percent of North American total operating refinery capacity was located in the US, the world's largest oil consumer. The shares of Canada and Mexico were, on average, 10 percent and 6.9 percent respectively over the same period. Figure A.1 presents the shares of each country in 1970, 2006 and the average over the period 1970–2006 to demonstrate the trend in expansion/contraction of refining capacity shares over time.

The figure indicates that while refining shares of both the US and Canada slightly decreased, Mexico's share more that doubled from 3.6 percent in 1970 to 8.0 percent in 2006. Similarly, while Mexico's 2006 refining share was higher than the overall 1970–2006 average, those of the US and Canada were both lower than average.

Similar to total capacity of operating refineries, total consumption of petroleum products rose from 16.7 million barrels per day in North America in 1970. However, unlike refining capacity, the overall 1970–2006 consumption peak occurred recently at 25.2 million barrels per day in 2005. Oil consumption tends to parallel the economic cycle and usually moves inversely with world oil prices. This explains a temporary downward trend in consumption in the late 1970s and early 1980s as well as a general upward trend afterwards up to the present times.

Figure A.1
Individual Country Shares in Total North American Operating Refinery Capacity, 1970, 2006 and Average over 1970–2006
(percent)



SOURCES: Calculated based on US data from Energy Information Administration (EIA) of US Department of Energy web site www.eia.doe.gov/emeu/aer/txt/stb0509.xls accessed in July 2007; data on Canada from Canadian Association of Petroleum Producers (CAPP), Statistical Handbook for Canada's Upstream Petroleum Industry, *July 2007; data on Mexico from various issues of* Oil & Gas Journal *for number of refineries; and Energy Information Administration of US Department of Energy web site accessed in August 2007, www. eia.doe.gov/emeau/aer/ inter.html and www.eia.doe.gov/emeu/aer/txt/ptb1109.html*

Figure A.2 depicts country consumption shares in 1970, 2006 and the average over 1970–2006. Together with the information in Figure A.1, they indicate that the US average consumption share was 84.2 percent, slightly higher than its 83.1 percent average refining share. Likewise, Mexico's average consumption share, 7.1 percent, was marginally lower than its 6.9 percent average refining share. However, Canada's average consumption share, 8.7 percent, was about 1.3 percent lower than it average 10.0 percent refining share.

Figure A.2 shows that Mexico's share of North American oil products consumption grew significantly from 3.0 percent in 1970 to 8.2 percent in 2006. Meanwhile, the consumption share of the US dropped by about 3.7 percentage points and that of Canada marginally decreased. Also, while Canada's 2006 consumption share was only marginally higher than the overall 1970–2006 average and Mexico's was close to 1.1 percent higher, that of the US was about 1.3 percent lower than its average.

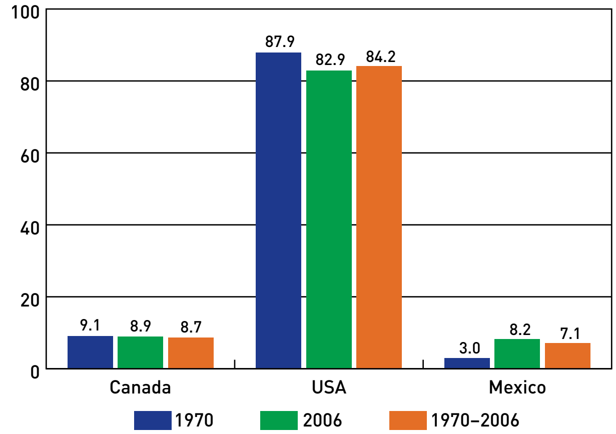
A.2 Comparison of Operating Refinery Capacity and Consumption

We now look at total North American refining capacity and compare it to the total regional consumption of refined petroleum products. As demonstrated in Figure A.3, total capacity of operating refineries was 13.9 million barrels per day in 1970 while total consumption was 16.7 million barrels per day in the same year, indicating that refining lagged behind consumption by about 2.8 million barrels per day.

Mostly thanks to the rapid expansion in the US refineries, this deficit turned into a surplus in 1980, refining capacity witnessed its all-time high of 22.2 million barrels per day in 1982, and excess refining capacity peaked at nearly 3.0 million barrels per day in 1982. However, due to government policies and technical/economic factors, refining capacity's 1970–1981 upward trend reversed into a sharp downward trend from 1982 to 1986 and refining capacity remained less than consumption throughout 1986–2006. Although refining capacity has regained a moderate overall upward trend since 1987, its recent 2006 level at 20.9 million barrels per day is still short of its all-time high by about 1.3 million barrels per day. In 2006, consumption

Figure A.2

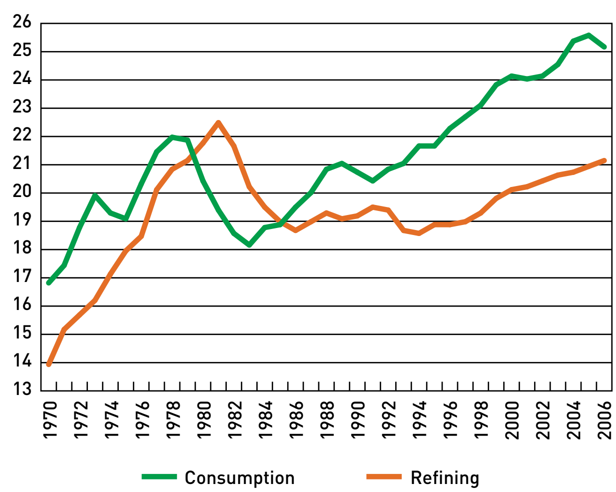
Individual Country Shares in Total North American Consumption of Petroleum Products, 1970, 2006 and Average over 1970–2006 (percent)



SOURCES: Calculated based on US data from Energy Information Administration (EIA) of US Department of Energy web site www.eia.doe.gov/emeu/aer/txt/stb0509.xls accessed in July 2007; www.eia.doe.gov/emeau/aer/inter.html: and www.eia.doe.gov/emeu/aer/txt/ptb1109.html accessed in August 2007.

Figure A.3

Capacity of Operating Oil Refineries and Total Oil Consumption in North America, 1970–2006 (millions barrels per day)



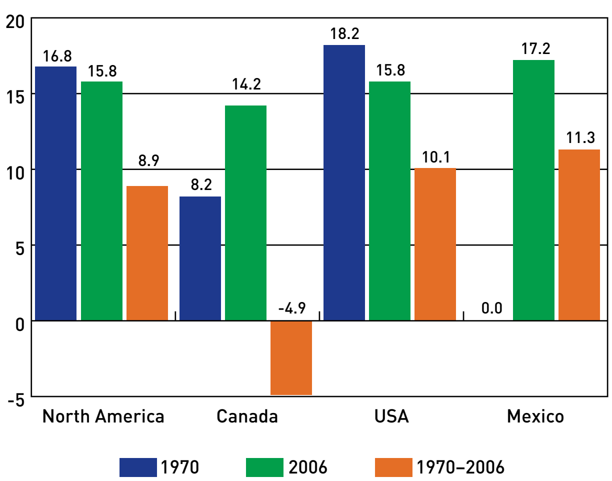
SOURCES: Calculated based on US data from Energy Information Administration (EIA) of US Department of Energy web site www.eia.doe.gov/emeu/aer/txt/stb0509.xls accessed in July 2007; data on Canada from Canadian Association of Petroleum Producers (CAPP), Statistical Handbook for Canada's Upstream Petroleum Industry, *July 2007; data on Mexico from various issues of* Oil & Gas Journal *for number of refineries; and Energy Information Administration (EIA) of US Department of Energy web site accessed in August 2007, www. eia.doe.gov/emeau/aer/inter.html and www.eia.doe.gov/emeu/aer/txt/ptb1109.html* reached 24.8 million barrels per day, about 3.9 million barrels higher that total refining capacity.

What about the situation in individual countries? Figure A.4 compares refining and consumption in each North American country in light of the overall regional comparisons. The figure indicates that North American refinery capacity lagged behind consumption by an average 8.9 percent over 1970–2006, and the lag was wider by 1 percent in 2006 compared to the 1970 level.

In the year 1970 refining capacity was lower than the consumption level in the US and Canada. It was equal to consumption in Mexico. In 2006, refinery capacity lagged significantly behind consumption and the gap was wider than the 1970–2006 average in all of the countries.

Figure A.4

The Lag of Operating Refinery Capacity Behind Consumption: Percent (negative number denotes excess capacity) in North America and Individual North American Countries; 1970, 2006 and the Average over 1970–2006



SOURCES: Calculated based on US data from Energy Information Administration (EIA) of US Department of Energy web site www.eia.doe.gov/emeu/aer/txt/stb0509.xls accessed in July 2007; data on Canada from Canadian Association of Petroleum Producers (CAPP), Statistical Handbook for Canada's Upstream Petroleum Industry, *July 2007; data on Mexico from various issues of* Oil & Gas Journal *for number of refineries; and Energy Information Administration (EIA) of US Department of Energy web site accessed in August 2007, www.eia.doe.gov/emeau/aer/inter.html and www.eia.doe.gov/emeu/aer/txt/ptb1109.html*

In Mexico, refining capacity fully covered consumption in 1970 but lagged behind it by a significant 17.2 percent in 2006. The situation in Canada was somewhat different where there was an average 4.9 percent excess of refining capacity over consumption. However, in 2006, the 14.2 percent lag represented 19.1 percent deterioration in comparison to the average level. In the US, the 15.8 percent lag in 2007 was less than the 18.2 percent level in 1970 but it was higher than average by about 5.7 percent.

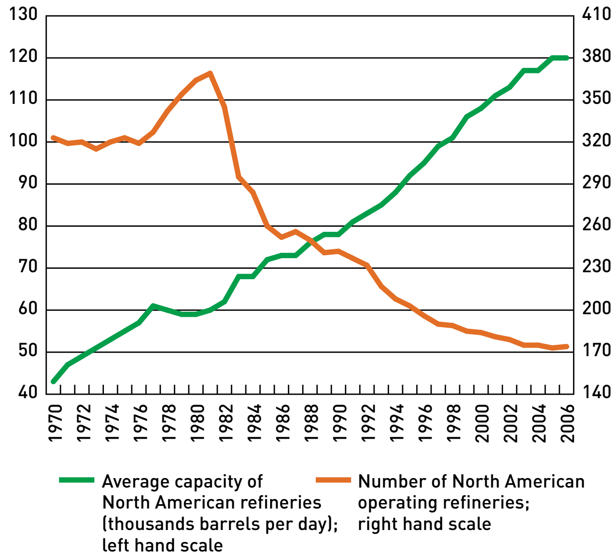
A.3 The Number of Refineries and Average Refinery Capacity

The changes in the number of North American refineries and their average capacity also reflect an interesting aspect of the developments in the refining sector. Figure A.5 indicates that the number of operating refineries in North America increased from 323 in 1970 to 369 in 1981 mostly due to the rapid expansion of the refinery sector in the US. However, the number has been basically declining from 1982 onwards, reaching its minimum, 173, in 2005 and then to only a slightly higher level, 174, in 2006. Meanwhile, progressively more stringent refined product quality standards calling for more sophisticated refining technologies and economies of scale have called for consolidation of smaller refineries into larger ones with wider ranges of refined products. Consequently, the average capacity of the operating refineries in North America has nearly tripled from a minimum 43,000 barrels per day in 1970 to a maximum 120,000 barrels per day in 2006.

Since the US holds the lion's share (about 82.9 percent in 2006) in total North American refining sector, the developments in the number and average capacity of its refineries closely explain the overall North American trend. In the early 1970s, in an effort to reduce inflation, oil prices in the US (along with the prices of many other products) were brought under federal government control. At the same time, in 1973, oil-exporting countries embargoed oil shipments to the US and reduced supplies to the world market, causing prices to increase dramatically. Overall price controls were removed in the mid-1970s, but were maintained on oil products.

Figure A.5

Number of North American Refineries and Their Average Capacity, 1970–2006 (thousands barrels per day)



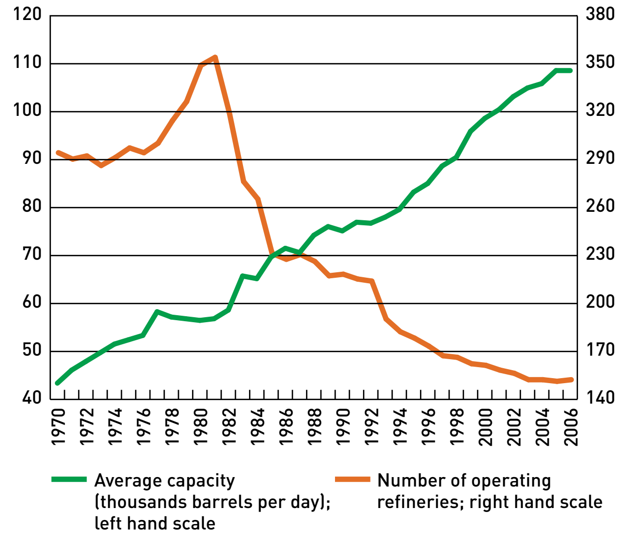
SOURCES: Calculated based on US data from Energy Information Administration (EIA) of US Department of Energy web site www.eia.doe.gov/emeu/aer/txt/stb0509.xls accessed in July 2007; data on Canada from Canadian Association of Petroleum Producers (CAPP), Statistical Handbook for Canada's Upstream Petroleum Industry, *July 2007; data on Mexico from various issues of* Oil & Gas Journal *for number of refineries; and EIA of US Department of Energy web site accessed in August 2007, www. eia.doe.gov/emeau/aer/inter.html and www.eia.doe.gov/emeu/aer/txt/ptb1109.html*

Refinery investment was artificially affected by the various US government programs that were intended to keep consumer oil prices from increasing. This market distortion encouraged construction of small refineries, most of which were not capable of producing the full broad spectrum of products, but which were given special protections in the marketplace. Most of these refineries would not have been profitable in competitive markets. As a result, the number of US operable refineries increased from 276 in 1970 to its all time high, 324, in 1981. Please refer to Figure A.6. In parallel, total refining capacity rose from 12.0 million barrels per day — its 1970–2006 low — in 1970, to 18.6 million barrels per day — its all time high — in 1981.

In 1981, oil price controls and protection for small US refiners were eliminated. As a result, many small US refineries subsequently closed. Since then, there has

Figure A.6

Number of US Refineries and Their Average Capacity, 1970–2006 (thousands barrels per day)



SOURCE: Energy Information Administration (EIA) of US Department of Energy web site http://eia.doe.gov/emeu/aer/txt.stb0509.xls accessed in July 2007.

been a steady decline in the number of North American operating refineries — an average of seven US refineries per year have closed since; bringing the number down to 149 in 2006 from 324 in 1981. Over the same time, the average size of US refineries has more than doubled from 57,472 barrels per day to 116,369; the smaller refineries closed, while the larger ones that continued to operate grew in size. No new refineries have been built since the early 1980s. Total US refining capacity, however, did not steadily decrease over 1981–2006. It dropped from 18.6 million barrels per day in 1981 to a minimum 15 in 1994; but it kept rising afterwards due to the growth in refined products demand to as high as 17.3 million barrels per day in 2006, still 1.3 million barrels per day lower than its historical maximum.

The increase in refining capacity has resulted from investment to expand existing sites, which has also lowered per unit costs of production. This has been achieved through increasingly sophisticated technology, streamlining operational management, de-bottlenecking facilities, and increasing operational efficiency.

APPENDIX B Natural Gas Pipeline Infrastructure

The American pipeline system was "designed" primarily to move gas from the Gulf Coast and mid-continent, either north into the Northeast and Midwest consuming regions, or west toward California.

Traditional flows are changing, however, as more supplies originate from the North and East. Frontier supplies — liquefied natural gas (LNG), Arctic gas, and Atlantic Canadian gas — now make up a larger share of the North American mix, and investments in the pipeline system designed to accommodate the new centres of supply will change flow patterns. With a more diverse geography of supply, the gas pipeline system is taking on more characteristics of hubs and networks; this has already occurred in the Midwest, is likely to happen in the Northeast, and is even developing within a few other supply regions such as Alberta (see Figure B.1).

Figure B.1
The North American Natural Gas Pipeline Infrastructure

APPENDIX C Conversion Factors

Table C.1

Thermal and Electric Power Equivalence

Energy Sources	Equivalence			
	Btus	Kilojoules	Kilocalories	Kilowatt Hour
One barrel of crude oil (bbl)	5,800,000	6,119,324	1,461,506	1,700
One tonne of crude oil	42,514,000	44,854,644	10,712,836	12,460
One cubic foot of natural gas (cf)	1,026	1,082	259	0.30
One cubic metre of natural gas	36,643	38,660	9,233	10.74
One tonne of coal	22,877,388	24,136,922	5,764,729	6,705
One pound of uranium (U_3O_8)	212,222,425	223,906,511	53,476,597	62,199
One kilo of uranium (U_3O_8)	467,870,360	493,629,360	117,895,715	137,125

SOURCES: British Petroleum (BP), Energy Information Administration (EIA) of US Department of Energy, University of California at Berkeley

Table C.2

Crude Oil Equivalence

	Crude Oil Equivalence	
Energy Sources	Barrels of Oil	Tonnes of Oil Equivalent (Toe)
1000 cubic feet of natural gas	0.18	0.024
One tonne of coal	3.94	0.538
One pound of uranium (U_3O_8)	36.59	5
One kilo of uranium (U_3O_8)	80.67	11

SOURCES: British Petroleum (BP), Energy Information Administration (EIA) of US Department of Energy, University of California at Berkeley

Table C.3

General Conversion Factors for Energy

To:	kJ	kcal	toe	Btu	kWh
From:	multiply by:				
Kilojoules (kJ)	1	0.2388344877	0.000000022294	0.947817122667	0.000277777778
Kilocalorie (kcal)	4.187	1	0.000000093346	3.968	0.001162790698
Tonne of oil equivalent (toe)	44,854,644	10,712,836	1	42,514,000	12,460
British thermal unit (Btu)	1.05505585	0.252016129032	0.000000023522	1	0.000293083236
Kilowatt hour (kWh)	3,600	860	0.000080255916	3,412	1

SOURCES: International Energy Agency (IEA) and British Petroleum (BP)

GLOSSARY of Key Terms

ACEEE: American Council for an Energy Efficient Economy.

AECL — Atomic Energy of Canada Limited: A nuclear technology and engineering company that designs and develops the CANDU nuclear power reactor, as well as other advanced energy products and services.

API: An American Petroleum Institute measure of specific gravity.

Ash: Impurities consisting of silica, iron, alumina, and other non-combustible matter that are contained in coal. Ash increases the weight of coal, adds to the cost of handling, affects the burning characteristics of the coal, and lowers its calorific value. The disposal of ash from coal-fired generating plants after combustion is costly.

Baseload: The minimum amount of electric power delivered or required at a steady rate over a given period of time.

Bcf/d: Billion standard cubic feet per day. Standard unit of measure of natural gas and LNG production or consumption.

Bituminous Coal: The most common coal. It is dense and black (often with well-defined bands of bright and dull material). Its moisture content usually is less than 20 percent.

Bitumen: Petroleum that exists in a semisolid or solid phase in natural deposits — it is the molasses-like substance that can comprise anywhere from 1 to 18 percent of oil sands.

Barrels of Oil Equivalent: A unit of volume equal to 42 US gallons.

Boiler: A device for generating steam for power, processing, or heating purposes, or for producing hot water for heating purposes or hot water supply. Heat from an external combustion source is transmitted to a fluid contained within the tubes in the boiler shell. This fluid is delivered to an end-use at a desired pressure, temperature, and quality.

British thermal unit (Btu): The standard unit of energy used in the United States. It equals 0.9478 kilojoules.

Calorific Value (Heat Content): The sum of latent heat and sensible heat contained in a combustible substance, above the heat contained at a specified temperature and pressure; expressed as joules per unit of volume or weight.

CANDU Reactor: Canadian Deuterium Uranium Reactor. A standardized design for nuclear generating stations developed in Canada. All nuclear generating units in Canada use the CANDU design.

Capability: The maximum load, in kilowatts or megawatts that a generating unit, generating plant, or other electrical equipment can carry under specified conditions for a given period of time without exceeding approved limits of temperature and stress.

Capacity Factor: The ratio of the electrical energy produced by a generating unit for a given period of time to the electrical energy that could have been produced at continuous full-power operation during the same period.

Capacity: The maximum power capability of a generating unit in kilowatts or megawatts.

Capital Expenditures: The amount of capital used during a particular period to acquire or improve long-term assets such as a generating unit or plant or piece of equipment.

CIPEC: Canadian Industry Program for Energy Conservation.

Coal: A black or brownish-black solid combustible substance formed by the partial decomposition of vegetable matter without access to air. The rank of coal, which includes anthracite, bituminous coal, sub-bituminous coal, and lignite, is based on fixed carbon, volatile matter, and calorific value.

Coal Bed Methane (CBM): Methane is generated during coal formation and is contained in the coal microstructure. Typical recovery entails pumping water out of the coal to allow the gas to escape. Methane is the principal component of natural gas. Coal bed methane can be added to natural gas pipelines without any special treatment.

Cogeneration: The simultaneous generation of electricity and another form of useful thermal energy (e.g. natural gas, biomass) used for industrial, commercial, heating, or cooling purposes.

Conventional Crude Oil: Petroleum found in liquid form, flowing naturally or capable of being pumped without further processing or dilution.

Conservation: Steps taken to cause less energy to be used than would otherwise be the case. These steps may involve improved efficiency, avoidance of waste, reduced consumption, etc. They may involve installing equipment (such as a computer to ensure efficient energy use), modifying equipment (such as making a boiler more efficient), adding insulation, changing behaviour patterns, etc.

Carbon Dioxide (CO_2): A colourless, odourless, non-poisonous gas that is a normal part of the earth's atmosphere. Carbon dioxide is a product of fossil-fuel combustion as well as other processes. It is considered a greenhouse gas as it traps heat (infrared energy) radiated by the earth into the atmosphere and thereby contributes to the potential for global warming.

CO_2 Emissions: The release of carbon dioxide during fuel combustion.

Combustion: The combining of oxygen with other elements through a chemical reaction that generates heat. Colloquially known as burning.

Cost of Spent Fuel Storage and/or Disposal: The cost of storing and/or disposing of nuclear fuel that has been used in a nuclear reactor to the point where it can no longer produce economic power.

Cost: The amount paid to acquire resources, such as plant and equipment, fuel, and labour and other services.

Crude Oil: A mixture of hydrocarbons that exists in liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities. Depending upon the characteristics of the crude stream, it may also include:

- Small amounts of hydrocarbons that exist in gaseous phase in natural underground reservoirs but are liquid at atmospheric pressure after being recovered from oil well (casinghead) gas in lease separators and are subsequently commingled with the crude stream without being separately measured. Lease condensate recovered as a liquid from natural gas wells in lease or field separation facilities and later mixed into the crude stream is also included.

- Small amounts of non-hydrocarbons produced with the oil, such as sulphur and various metals.

- Drip gases, and liquid hydrocarbons produced from tar sands, gilsonite, and oil shale.

- Liquids produced at natural gas processing plants are excluded. Crude oil is refined to produce a wide array of petroleum products, including heating oils; gasoline, diesel, and jet fuels; lubricants; asphalt; ethane, propane, and butane; and many other products used for their energy or chemical content.

Deep Panuke Field: A gas field that is trapped over a carbonate reef southeast of Halifax, Nova Scotia. The field is undergoing assessment for commercial exploitation.

Demand-Side Management (DSM): The planning, implementation, and monitoring of utility activities designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand. It refers only to energy and load-shape modifying activities that are undertaken in response to utility-administered programs. It does not refer to energy and load-shaped changes arising from the normal operation of the marketplace or from government-mandated energy efficiency standards. Demand-side management covers the complete range of load-shape objectives, including strategic conservation and load management, as well as strategic load growth.

Density: The heaviness of crude oil, indicating the proportion of large, carbon-rich molecules, generally measured in kilograms per cubic metre (kg/m^3) or degrees on the American Petroleum Institute (API) gravity scale; in Western Canada oil up to 900 kg/m^3 is considered light to medium crude — oil above this density is deemed as heavy oil or bitumen.

Economic Life: The time period of commercial operation of an asset that is assumed for the purpose of economic and/or financial evaluation of the asset.

Efficiency: The efficiency of a generating unit in converting the thermal energy contained in a fuel source to electrical energy. It is expressed as a percentage and equals 3.6 divided by the heat rate of the unit (in GJ/MWh).

EII: Energy Innovators Initiative.

Electrical Energy: The quantity of electricity produced over a period of time. The commonly used units of electrical energy are the kilowatt-hour (kWh), megawatt-hour (MWh) and gigawatt-hour (GWh).

Electric Vehicle: A motor vehicle powered by an electric motor that draws current from rechargeable storage batteries, fuel cells, photovoltaic arrays, or other sources of electric current.

Electrical Power: The rate of delivery of electrical energy and the most frequently used measure of capacity. The typical basic units of electrical power are the kilowatt (kW) and megawatt (MW).

Emissions: Anthropogenic releases of gases to the atmosphere. In the context of global climate change, they consist of important greenhouse gases (e.g. the release of carbon dioxide during fuel combustion).

Emissions Cost: The cost associated with the release or discharge of a substance into the environment; generally refers to the cost associated with the release of gases or particulates into the air.

End-User: A firm or individual that purchases products for its own consumption and not for resale (i.e. an ultimate consumer).

Energy: The capability for doing work (potential energy) or the conversion of this capability to motion (kinetic energy). Energy has several forms, some of which are easily convertible and can be changed to another form useful for work. Most of the world's convertible energy comes from fossil fuels that are burned to produce heat that is then used as a transfer medium to mechanical or other means in order to accomplish tasks.

Energy Consumption: The amount of energy consumed in the form in which it is acquired by the user. The term excludes electrical generation and distribution losses.

Energy Demand: The requirement for energy as an input to provide products and/or services.

Energy Efficiency: Refers to reducing the energy used by specific end-use devices and systems, typically without affecting the services provided. Examples include high-efficiency appliances, efficient lighting programs, high-efficiency heating, ventilating and air conditioning (HVAC) systems or control modifications, efficient building design, advanced electric motor drives, and heat recovery systems.

Energy Intensity: The amount of energy it takes to produce a dollar of gross domestic product.

ERCOT: Electric Reliability Council of Texas.

Exajoule: Unit of energy, 10^{18} joules, often used as unit of measure for world annual energy use. Comparable in size to a quad (1 EJ = 0.948 quads).

Extraction: The process of separating the bitumen from the oil sands.

Expenditure: The incurrence of a liability to obtain an asset or service.

Facility: An existing or planned location or site at which prime movers, electric generators, and/or equipment for converting mechanical, chemical, and/or nuclear energy into electric energy are, or will be, situated. A facility may contain generating units of either the same or different prime mover types.

Fast Breeder Reactors: This process allows the extraction of up to 100 times the amount of energy from uranium than is possible using light water reactors.

FBI: Federal Buildings Initiative.

FERC: Federal Energy Regulatory Commission.

Fossil Fuel: Any naturally occurring organic fuel, such as coal, oil, and natural gas.

Fossil-Fuel Unit: A generating unit using coal, oil, gas, or another fossil fuel as its source of energy.

Fuel Cell: A device capable of generating an electrical current by converting the chemical energy of a fuel (e.g. hydrogen) directly into electrical energy. Fuel cells differ from conventional electrical cells in that the active materials such as fuel and oxygen are not contained within the cell but are supplied from outside. It does not contain an intermediate heat cycle, as do most other electrical generation techniques.

Fuel Price: The price of fuel used in a generating unit, at the point of purchase. It is expressed here in dollars per gigajoule ($/GJ). In some cases, it is derived from the price of fuel expressed in dollars per unit of weight or volume (e.g. $/tonne of coal) and the corresponding calorific value (e.g. GJ/tonne).

Fuel: Any substance that can be burned to produce heat. It is also a material that can be fissioned in a nuclear reaction to produce heat.

Fuel Switching: The substitution of one type of fuel for another, especially the use of a more environmentally friendly fuel as a source of energy in place of a less environmentally friendly one.

Gas Hydrates: Crystalline solid; its building blocks consist of a gas molecule surrounded by a cage of water molecules.

Gas (or Combustion) Turbine: A generating unit in which the prime mover is a gas turbine. A gas turbine consists typically of an axial-flow air compressor and one or more combustion chambers, where liquid or gaseous fuel is burned and the hot gases are passed to a turbine where the hot gases expand to drive a generator to produce electricity.

Generating Unit: Any combination of physically connected reactor(s), boiler(s), combustion turbine(s), or other prime mover(s), generator(s), and auxiliary equipment operated together to produce electricity.

Generating Plant: A facility containing one or more generating units.

Generation: The process of producing electrical energy by transforming other forms of energy.

Generation Mix: Term for the diversity of generating units used to produce electricity. For example, a region's generation mix might include 35 percent hydroelectricity, 35 percent nuclear and 30 percent coal-fired energy.

Generator: A machine that converts mechanical energy into electrical energy.

Geothermal Energy: Heat stored within the earth. Once captured, such heat can be used for space heating and electricity generation.

Gigajoule (GJ): One billion joules.

Gigawatt (GW): One billion watts.

Gigawatt-Hour (GWh): One billion watt-hours.

Global Warming: The theoretical escalation of global temperatures caused by the increase of greenhouse gas concentrations in the lower atmosphere.

Greenhouse Effect: The increasing mean global surface temperature of the earth caused by gases in the atmosphere (including carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons). The greenhouse effect allows solar radiation to penetrate but absorbs the infrared radiation returning to space.

Greenhouse Gases (GHGs): A collection of gaseous substances, primarily consisting of carbon dioxide, methane, and nitrogen oxide that have been shown to warm the earth's atmosphere by trapping solar radiation. Greenhouse gases also include chlorofluorocarbons (CFCs), a group of chemicals used primarily in cooling systems and which are now either outlawed or severely restricted by most industrialized nations.

Gross Domestic Product (GDP): Total economic output in a given country.

Gross Generation: The electrical energy production of a generating plant or unit before subtracting station service, expressed in megawatt-hours (MWh) or gigawatt-hours (GWh).

Grid: The layout of an electrical transmission and/or distribution system.

Gross National Product (GNP): GDP plus local ownership share of GDP in the rest of the world less rest of the world's ownership share of local GDP.

Gypsum: Calcium sulphate, a mineral used for wallboard and as a soil amendment in consolidated tails technology.

Heat Content: (See Calorific Value.)

Heat Rate: A measure of the efficiency of energy conversion of a generating unit or plant. It is the ratio of the heat content of the fuel used (expressed in kJ or Btu) in the unit or plant to kWh of net electrical energy produced.

Heavy Oil: Dense, viscous oil, with a high proportion of bitumen, which is difficult to extract with conventional techniques and is more costly to refine.

Hibernia: The Hibernia field, which was discovered in 1979, is located about 315 kilometres east-southeast of St. John's, Newfoundland, in 80 metres of water. A fixed production platform, consisting of a Gravity Base Structure (GBS) and Topsides drilling and production facilities, has been installed to produce the field.

Hydrocarbons: A large class of liquid, solid, or gaseous organic compounds, containing only carbon and hydrogen, which are the basis of almost all petroleum products.

Hydroelectric Power: Electricity produced by falling water that turns a turbine generator. Also referred to as hydro.

Hydrogen: A colourless, odourless, highly flammable gaseous element. It is the lightest of all gases and the most abundant element in the universe, occurring chiefly in combination with oxygen in water and also in acids, bases, alcohols, petroleum, and other hydrocarbons.

Hydrophilic: Describes a substance that attracts, dissolves in, or absorbs water.

IEA: International Energy Agency.

In Situ: In its original place; in position; in situ recovery refers to various methods used to recover deeply buried bitumen deposits, including steam injection, solvent injection, and firefloods.

Installed Capacity: The capacity measured at the output terminals of all the generating units in a plant, before deducting power requirements for station service.

Integrated Gasification-Combined Cycle Technology (IGCC): Coal, water, and oxygen are fed to gasifier, which produces syngas. This medium-Btu gas is cleaned (particulates and sulphur compounds removed) and is fed to a gas turbine. The hot exhaust of the gas turbine and heat recovered from the gasification process are routed through a heat-recovery generator to produce steam, which drives a steam turbine to produce electricity.

Intermediate Load: The range of power system loads between baseload and peak load.

Intermittent Power Source: A generator, such as a wind turbine, whose output may vary considerably over short periods due to the variability and unpredictability of its external energy source.

Joule: The international unit of energy. It is the energy produced by the power of one watt operating for one second. At 100 percent efficiency, there are 3.6 megajoules in a kilowatt-hour (or 3.6 gigajoules in a megawatt-hour).

Kilowatt (kW): A standard unit used to measure electric power, equal to 1,000 watts. A kilowatt can be visualized as the total amount of power required to light ten 100-watt light bulbs.

Kilowatt-Hour (kWh): A standard unit for measuring electrical energy.

Kyoto Protocol: The Kyoto Protocol is a proposed amendment to an international treaty on global warming — the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol will commit to reducing their emissions of carbon dioxide and other greenhouse gases, which are linked to global warming.

Light Fuel Oil: Lighter fuel oils distilled off during the refining process. Virtually all petroleum products used in internal combustion and gas turbines are light fuel oil.

Lignite: A brownish-black coal of low rank with high inherent moisture and volatile matter content.

Liquefied Natural Gas (LNG): Natural gas (primarily methane) that has been liquefied by reducing its temperature to minus 260 degrees Fahrenheit at atmospheric pressure.

Load: The amount of electricity demand at any specific point or points on a power system. The amount originates at the energy-using equipment of consumers.

Megawatt (MW): One million watts.

Megawatt-Hour (MWh): One million watt-hours.

MMbbl/d: Millions of barrels per day. Unit of measure of crude oil and petroleum products.

MMBtu: Millions of British thermal units.

Mcf: Millions of cubic feet. Unit of measure of natural gas and gas products.

Mtoe: Millions of tonnes oil equivalent.

Muskeg: A water-soaked layer of decaying plant material, one to three metres thick, found on top of the overburden.

NAFTA: North American Free Trade Agreement.

Nameplate Capacity: The full-load continuous rating of a generator, prime mover, or other electric power production equipment, under specific conditions as designated by the manufacturer. Installed nameplate rating is usually indicated on a nameplate physically attached to the piece of equipment.

Natural Gas: A naturally occurring mixture of hydrocarbon and non-hydrocarbon gases found in porous geological formations beneath the earth's surface, often in association with petroleum. The principal constituent is methane. It is used as a fuel in boilers and gas turbines for electricity generation.

NERC: North American Electricity Reliability Council.

Net Capability: The maximum ability of a generating unit or plant, under specified conditions, to meet electricity demand. It is the capability of the generating equipment minus station service. It is usually expressed in megawatts (MW).

Net Generation: Gross generation of a generating unit or plant minus station service, expressed in megawatt-hours (MWh) or gigawatt-hours (GWh).

NRCan: Natural Resources Canada.

Nuclear Electric Power (Nuclear Power): Electricity generated by the use of the thermal energy released from the fission of nuclear fuel in a reactor.

Nuclear Fission: The process of splitting atoms or fissioning them.

Nuclear Fuel: Fissionable materials that have been enriched to such a composition that, when placed in a nuclear reactor, will support a self-sustaining fission chain reaction, producing heat in a controlled manner for process use.

Nuclear Power Plant: A generating plant in which heat produced in a nuclear reactor by the fissioning of nuclear fuel is used to drive a steam turbine.

Nuclear Reactor: A device in which a fission chain reaction can be initiated, maintained, and controlled. Nuclear reactors are used in the power industry to produce steam used for the generation of electricity.

OECD: Organisation for Economic Co-operation and Development.

Oil Sand: Sand containing bitumen.

OPEC: Organization of Petroleum Exporting Countries.

Overburden: Layer of rocky, clay-like material that lies under muskeg.

Peak Load Plant (or Unit): A generating plant (or unit) that normally operates intermittently during the hours of highest (peak) daily, weekly, or seasonal power system loads.

Peaking Capacity: Capacity of generating equipment normally reserved for operation during peak load periods.

Petróleos Mexicanos (PEMEX): Largest company in Mexico and the world's seventh largest petroleum company.

Petroleum: A naturally occurring mixture composed predominantly of hydrocarbons in the gaseous, liquid, or solid phase.

Petroleum Administration for Defence District (PADD): A geographic aggregation of the 50 states and the District of Columbia into five districts, with PADD I further split into three sub-districts. The PADDs include the states listed below:

PADD I (East Coast):

PADD IA (New England): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

PADD IB (Central Atlantic): Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania.

PADD IC (Lower Atlantic): Florida, Georgia, North Carolina, South Carolina, Virginia, and West Virginia.

PADD II (Midwest): Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, and Wisconsin.

PADD III (Gulf Coast): Alabama, Arkansas, Louisiana, Mississippi, New Mexico, and Texas.

PADD IV (Rocky Mountain): Colorado, Idaho, Montana, Utah, and Wyoming.

PADD V (West Coast): Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington.

Photovoltaic (PV) Cells: Convert sunlight directly into electricity.

Power: The rate at which energy is produced. Electrical energy is usually measured in watts.

Power System: All the physically interconnected facilities of an electrical utility, or a number of interconnected utilities. A power system includes all the generation, transmission, distribution, transformation, and protective components necessary to provide service to consumers.

Price: The amount of money or consideration-in-kind for which a good or service is bought, sold, or offered for sale.

Primary Energy: Energy embodied in natural resources (e.g. coal, crude oil, sunlight, uranium) that has not undergone any anthropogenic conversion or transformation.

Prime Mover: The engine, turbine, water wheel, or similar machine that drives an electric generator.

Profit: The income remaining after all business expenses are paid.

Proved Energy Reserves: Estimated quantities of energy sources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. The location, quantity, and grade of the energy source are usually considered to be well established in such reserves.

Quad: Quadrillion (10 to the 15th power) Btus.

Radioactive Waste: Materials left over from making nuclear energy. Radioactive waste can destroy living organisms if it is not stored safely.

Refinery: An installation that manufactures finished petroleum products from crude oil, unfinished oils, natural gas liquids, other hydrocarbons, and oxygenates.

Renewable Energy: Any sources or resources of energy that constantly renew themselves through natural processes, that can be renewed artificially, or that are regarded as practically inexhaustible. These include solar, wind, geothermal, hydro, and wood resources. Although particular geothermal formations can be depleted, the natural heat in the earth is a virtually inexhaustible reserve of potential energy. Renewable resources also include some experimental or less-developed sources such as tidal power, sea currents, and ocean thermal gradients.

Residuum: A residual product from the processor distillation of hydrocarbons.

Resources for the Future (RFF): A think tank in Washington, D.C.

Separative Work Unit (SWU): A standard measure of uranium enrichment services.

Security of Supply: Policy that considers the risk of dependence on fuel sources located in remote and unstable regions of the world and the benefits of domestic and diverse fuel sources.

SMD: Standard market design.

Spent Fuel: Nuclear fuel removed from a reactor following irradiation, no longer usable in its current form because of depletion of fissile material, poison build-up or radiation damage.

Station Service: The electric energy used in the operation of a generating plant or unit. This energy is subtracted from the gross generation to obtain net generation.

Steam-Assisted Gravity Drainage (SAGD): A recovery technique for extraction of heavy oil or bitumen that involves drilling a pair of horizontal wells one above the other; one well is used for steam injection and the other for production.

Steam-Electric Unit: A plant in which the prime mover is a steam turbine. The steam used to drive the turbine is generated in a boiler where fossil fuels are burned, or by heat produced in a nuclear reactor by the fissioning of nuclear fuel.

Sub-Bituminous Coal: Sub-bituminous coal, or black lignite, is dull black and generally contains 20 to 30 percent moisture.

Sunk Cost: A cost that was incurred in the past and cannot be altered by any current or future decision.

Sustainability: Indicator selected with the aim to provide information on the essence of sustainable development; it may refer to systemic characteristics such as carrying capacities of the environment, or it may refer to interrelations between economy, society, and the environment.

Synthetic Crude Oil: A mixture of hydrocarbons, similar to crude oil, derived by upgrading bitumen from oil sands.

Tailings: A combination of water, sand, silt, and fine clay particles that are a by-product of removing the bitumen from oil sands.

Tcf: Trillions of cubic feet.

Thermal Efficiency: The percentage of total energy content of a fuel that is converted to useful output. The ratio of useful work (or energy output) to total work (or energy input).

Tight Sands: Low-permeability gas.

Toe-to-Heal Air Injection (THAI): A process that uses air injection and subsurface combustion to increase mobility in the reservoir.

TPES: Total primary energy supply.

Turbine: A machine for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, or hot gas). Turbines convert the kinetic energy of fluids to mechanical energy through the principles of impulse or reaction, or a mixture of the two.

TWh: Terawatt-hours (billions of kilowatt-hours).

Unit (or Plant) Availability: The number of hours a generating unit is available to produce power (regardless of the amount of power) in a given period, compared to the number of hours in the period.

Upgrading: The process of converting heavy oil or bitumen into synthetic crude oil.

Uranium (U): A heavy, naturally radioactive, metallic element (atomic number 92). Its two principally occurring isotopes are uranium-235 and uranium-238. Uranium-235 is indispensable to the nuclear industry because it is the only isotope existing in nature, to any appreciable extent, that is fissionable by thermal neutrons. Uranium-238 is also important because it absorbs neutrons to produce a radioactive isotope that subsequently decays to the isotope plutonium-239, which also is fissionable by thermal neutrons.

US EIA: United States Energy Information Administration.

Vapour Extraction: The use of solvents to reduce bitumen viscosity in situ.

Viscosity: The resistance to flow or "stickiness" of a fluid.

Volatility: In financial matters, volatility of returns is the measurement used to define risk. The greater the volatility, the higher the risk.

Watt: The standard unit of electrical power. One watt is equal to one joule per second. It also equals one ampere flowing under a pressure of one volt at unit power factor.

Watt-Hour (Wh): The standard unit of electrical energy. It is equal to one watt of power operating steadily for one hour.

WCSB: Western Canada Sedimentary Basin.

WECC: Western Electricity Coordinating Council.

West Texas Intermediate (WTI): A grade of crude oil that has its main delivery point in Cushing, OK. The spot price for WTI delivered Cushing is the ultimate settlement price for the NYMEX oil futures contract.

Wholesale Power Market: The purchase and sale of electricity from generators to resellers (who sell to retail customers) along with the ancillary services needed to maintain security of service and power quality at the transmission level.

Wholesale Price: The price of energy supplied to electric utilities and other power producers.

Wind Generator: A generator that obtains its power from wind turning a wind turbine.

Sources for the Glossary

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Clean Coal Technology Compendium: www.lanl.gov/projects/cctc/resources/library/glossary/glossaryf.html

California Energy Commission Glossary: www.energy.ca.gov/glossary/index.html

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