The Coming Three Peaks in the World Energy System and their Relationship to Climate Change and Poverty

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Abstract

Three peaks are expected in the energy system in the coming half-century. World population is expected to peak about 2050, world conventional oil production in the 2017-20 period, and North American conventional natural gas production by 2010 at the latest. This paper examines the consequences of these peaks in terms of possible scenarios for three time intervals each of which faces different issues. *Interval 1* deals with the period up to 2020; *Interval 2* for 2020 to 2050; and *Interval 3* after 2050.

A deep 'V' is expected in the price of oil in *Interval 1* after the situation in Iraq is resolved and before the coming peak in production of conventional oil. The period of low oil prices is expected to coincide approximately with the peak in North American conventional natural gas production. The consequences of such a scenario are discussed in terms of the effect upon electrical generation.

Two major complicating and contradictory issues are important through all three intervals: the need to reduce emissions of greenhouse gases to the atmosphere and the alleviation of poverty around the globe which will require an increase in energy consumption, especially electricity, in developing countries.

Introduction

Three peaks of importance are expected on the world energy scene within the coming decades. These are listed below in the reverse order of their anticipated timing:

- world population will peak at about eight billion people by 2050-55 according to the most recent United Nations and IIASA studies (Range: 7.5-8.5 billion);

- world production of conventional oil is expected to peak about 2020 by this author (Range: 2017-26);[1] and

- North American production of natural gas from conventional sources will peak the earliest of the three no later than 2010 if it has not already reached its maximum. (Range: 2003-2010).

The behaviour of the energy economy of the world in the next half-century will be largely defined by these three peaks over this period of time. This paper has been prepared to explore the relationships among them and the likely consequences that follow.

Peaks have occurred in the energy system before. It is useful to review three from the past in their chronological order to aid in the assessment of the significance of the three expected in the future. First, oil production in the U.S. peaked about 1971 and never recovered despite the many advances in exploration and production techniques since that time though production may increase again somewhat over the next few years with the exploitation of the deep resources of the Gulf of Mexico. Second, world oil consumption per capita derived from all sources (which is effectively equal to the world production of conventional oil per capita) fell from a peak of 5.45 barrels per capita in 1973 to level off at a nearly constant average value of 4.47 barrels per capita for the last 19 years.[2] The decline in per capita consumption of conventional oil is expected to resume soon over a wide range of production and population assumptions.[3] Third, conventional oil production from the Western Canada Sedimentary Basin—the main source of domestic petroleum for this nation—peaked in the 1990s reflecting the maturity of the WCSB since the modern oil era began with the Leduc discovery in Alberta in 1947. No special event marked these three past peaks as each was passed in turn. More often each peak was either ignored or even denied for several years after its occurrence. All three past peaks had little effect on consumers in a practical sense and, in fact, were little noticed at the time although their passage was of importance to the planning of the exploration industry. Nevertheless, each serves as an early warning signal of the more serious situation that is to come.

The continuing growth in world population remains the underlying force driving the increase in the consumption of all material goods including oil, and this constant pressure will become more acute after the peak in world oil production from conventional sources has passed.[3] The intractability of the world problem may be summarized this way: the population peak comes only after the other two peaks have passed. The problem is how to get through the next fifty years.

It will be difficult enough to deal with this situation on its own but now the urgent need to cope with two other issues at the same time complicates matters greatly. The emissions of carbon dioxide and other greenhouse gases from the fossil fuels to the atmosphere must be reduced substantially over this period. The minimum objective at the end of the next fifty years is to aim at the stabilization of concentrations of greenhouse gases in the atmosphere. To meet this target requires a reduction from present emissions of about 60%—a target that will be very difficult to attain. This problem is compounded by the equally urgent necessity to reduce poverty among the developing nations where most of the population growth will occur in the future. Greater economic growth in those nations requires the local consumption of more energy, especially electricity, not less. This additional energy must thus be supplied at a time when the emissions of carbon dioxide must be reduced.

At first glance the situation would appear to be almost hopeless. There is, however, one positive aspect. The coincidence of the world peak in the production of conventional oil with the need to reduce emissions suggests the direction of a possible solution. The impending peak makes the environmental objective easier to attain by causing energy prices to rise with the result benign but more costly sources of energy (wind, solar, etc.) become more competitive. The higher price will also encourage ways of using energy more efficiently with an important current example being the introduction of light emitting diodes (LEDs). With more incentive to improve these technologies, there should be more rapid advances to reduce costs on either side of the supply/demand balance. The problem then becomes one of supplying additional energy in more benign forms to developing countries at a cost low enough to raise living standards. The danger is that higher energy prices will lower standards still further.

Chapter 13 of the International Energy Agency's *World Energy Outlook 2002* titled *Energy and Poverty* was prepared in advance of publication of the full report in time for discussion at the World Summit on Sustainable Development held in Johannesburg, South Africa, 28 August to 4 September 2002.[4] This Chapter deals with the importance of providing the poor with better access to additional energy supply, particularly electricity, in addressing this issue. The IEA is surely right when it states that the lack of electricity exacerbates poverty and contributes to its perpetuation, as it precludes most industrial activities and the resulting related economic development.

This paper examines in more detail the relationships likely to unfold as the world approaches and passes through the watershed period between the peak in conventional oil production and the peak in world population. After 2050, with population slowly decreasing, this difficult situation may well begin to ease particularly as the new technologies are perfected and deployed. The main problem becomes how to reach 2050 without serious disruptions. During this difficult intermediate period, there are two specific requirements: first, the world will need an economic source of electricity that does not require petroleum products in its generation or otherwise lead to an increase in emissions of greenhouse gases; and, second, it will need a way of powering the growing number of vehicles in such a way that an intolerable burden is not placed on the oil supply system as it becomes highly stressed.

At the present time, the answer to the first requirement is some mix of electrical generation from renewable energy (mainly wind and solar), from improved fission reactors in the nuclear field, and from generation based upon coal with the capture and sequestering of the carbon dioxide produced. Even with the widespread introduction of cogeneration and other forms of distributed generation ranging from mini turbines to fuel cells and based mainly upon natural gas, it is difficult to see how the world can proceed without these three forms of centralized electrical supply. As for the second need, given success in meeting electrical requirements in a benign way, it may be that the widespread use of hybrid-powered vehicles may save enough oil to avoid shortages provided other forms of energy are available to continue its gradual displacement from stationary applications. Given some degree of success, the major deployment of hydrogen or methanol-based fuel cell equipped cars, with the related need for, in effect, a new energy production and distribution system, may be delayed until later in the century.

This subject is explored in this paper by examining possible scenarios in the periods between the three peaks that have been identified. Detailed sections follow these scenarios to amplify and clarify certain specific aspects of this subject.

Likely Scenarios for the Intervals Between Peaks

Three future periods of interest will be considered separately here because of the different circumstances pertaining to each:

Interval 1 - the period before the peak in the world production of conventional oil is reached (the years from the present to 2017-~2020);

Interval 2 - the period between the peaks in world conventional oil production and population (~2020-2050); and

Interval 3 - the period after the world population has stabilized and begins to decline (after 2050).

Interval 1 (Present to 2017/ ~2020):

During the immediate future, there is the strong possibility of a deep `V'-shaped trend in the price of oil as a consequence of the resolution of the crisis centred on Iraq for the reasons discussed in detail below on the section devoted to the possible effects of this conflict. There is also a good possibility that the minimum price for oil will coincide approximately with the peak in the production of conventional natural gas in North America. The gas peak in this Continent taken as a whole is likely to occur between 2003-10 if it has not already. The incentive to substitute oil products for natural gas in many applications would be the greatest at this point. This coincidence of lower oil prices and higher natural gas prices in North America would tend to cause greenhouse gas emissions to increase in two different ways because of (1) the direct substitution of higher-carbon oil products for the lower-carbon gas, and (2) from meeting the higher demand for electricity arising indirectly from the greater economic growth stimulated by the period of lower oil prices. There will also be a tendency to use more electricity in space heating markets.

Much of the growth in electrical demand will be met by generation in new combined-cycle installations built originally for fuelling with natural gas. The longer the period of low oil prices persists, the greater will be the tendency to convert these new stations to operation on liquid turbine fuels with the result that carbon dioxide emissions increase more than anticipated in generation. Moreover, with higher than expected electrical demand, there will also be an incentive to keep older coal-fired installations in service longer than planned through the implementation of the life extension technologies. These effects taken together will offset the reduction in emissions arising from the still small but growing wind power or other renewable options introduced for the generation of electricity during this Interval.

In the transportation field, the period of low oil prices will slow the introduction of both the low-emission hybrid engine systems and the rarer hydrogen options being developed for cars whether this gas is used in internal combustion engines or in fuel cells. Measures implemented during this interval to reduce greenhouse gas emissions tend to reduce oil prices below what they would have been otherwise: these prices have a long way to fall before there would be an appreciable decrease in oil supply.

In the longer-term, a period of low oil prices will discourage expansion of additional supply from the Alberta oil sands industry as well as from the eastern off-shore and northern regions in Canada. Low prices will also result in the gradual shutting-in of production from low-output `stripper' wells in the U.S. and from other oil producing regions such as the Western Canada Sedimentary Basin and other mature basins around the world. For this reason, the period of low prices will be self-correcting and an increase should be underway no later than 2010, given a steady but slow growth in demand by historical standards.

With the typical rates employed in discounting calculations, trading markets should begin to detect the approach of the world peak in conventional oil production about ten years before and no later than 2010. (Discounting turns blind over a decade at the usual range of rates employed in these calculations.) The current uncertainty over the ultimate extent of the world endowment of conventional oil should also be nearer to resolution at this time.

During Interval 1, the emission targets set under the Kyoto Protocol will be difficult to meet primarily because of the lower than expected price for oil. In more general terms, the technical cost of most conventional production around the world is so low that is difficult to conceive of a situation where this oil would not be ultimately consumed: the best one can hope for is a reduction in the speed of its production.

The advantage of the period of low oil prices during Interval 1 is that the rate of economic growth should be higher than would otherwise be the case. This period thus provides an opportunity to assist those countries that need more energy, particularly electricity, to overcome poverty. The world should make every effort to take advantage of this situation but the inevitable penalty will be greater emissions than expected during this Interval.

Interval 2 (2020 to 2050):

Once the peak in conventional oil production is reached, the minimum price of oil will depend upon the cost of its cheapest alternative on either the supply or demand side. A higher but more stable price structure will result because it is unlikely a recession would be severe enough to reduce the supply of the more costly non-conventional oil production entirely. This stability will make it possible to prepare more rationally for a reduction in the emissions of carbon dioxide and the other greenhouse gases.

Unlike the situation before the peak in Interval 1, there should only be minor decreases, if any, in the price of oil caused by measures imposed to reduce the emissions of the greenhouse gases. The major difference between Intervals 1 and 2 may be stated this way: after the peak, the introduction of successful measures to reduce emissions will not cause the price of oil to fall. Also, because of the wide gap between the low technical cost of production of conventional oil and its more costly substitutes, very high returns will accrue to the owners of the still remaining large resources of conventional oil: this large economic rent will present a vexing problem for policymakers during this period.

There are two main concerns during Interval 2. The first is the possibility of a periodic crisis situation arising from physical shortages of oil products. The second concern is the possibility that the higher prices combined with the ability of richer countries to outbid poorer ones will prove a serious setback to the efforts to reduce poverty around the world.

If physical shortages do in fact develop from time-to-time in Interval 2, there will be a tendency to invoke simultaneous measures out of order of a rising cost curve on either the supply or the demand side particularly if the lower cost options take longer to deploy than the more costly ones. This effect is always a problem on the supply side but it may also prove to be the case for certain conservation efforts. For example, the introduction of highly efficient new lighting systems based upon light emitting diodes (LEDs) might be delayed by the forced rapid deployment of more readily available alternatives such as compact fluorescent lamps. Because the savings curve would not be a smooth function in this situation, the energy system would again return to the lack of internal equilibrium characteristic of the first Interval. If so, the consequence would be greater difficulty in reducing greenhouse emissions in a rational stage-wise least-cost manner.

The second concern arises from the problems more expensive energy, including electricity, will cause for the developing world. It is to be hoped by that time the major renewable options—wind, solar and biomass generation—will be farther advanced. Nevertheless, it is difficult to see how this extra electricity can be provided to the large and growing urban conurbations becoming more common around the world without the further development of nuclear power and modern coal-based generation equipped for full environmental protection including the capture and sequestration of carbon dioxide.

Interval 3 – From 2050 On

Once the world's population reaches its peak and begins to slowly fall, the energy system will begin to relax from the near crisis mode of operation characteristic of Interval 2. The production of conventional oil in this period will be falling rapidly and the situation will be complicated by the approach of the peak in output of conventional natural gas on a world basis by about 2050 if it does not occur sooner. Given the successful development of processes for the capture and sequestering of carbon dioxide, the large resources of coal still available in many countries will serve as a bridge to provide time for the introduction of the new technologies that will surely be available by then.

With the assumption that the world will avoid chaos somehow, many long-standing problems will be, if not fully resolved by that time,at least reduced to a manageable level. The relief of extreme poverty implies that the electrical problem will have been solved in one way or another as will be the supply of at least a minimal level of food to everyone. This implies that the related water problem will also be addressed by then.

After 2050, the urgency of the climate change problem will be clear as will be the extent of the effort required to deal with it. Nevertheless, regardless of the severity of this situation at that time, it is assumed here that geoengineering techniques would not be invoked to deal with global climate change. These global techniques vary from the supply of electricity in microwave form from space-based satellites to methods for enhancing the transfer of carbon dioxide to the oceans by techniques that increase the passage of this gas across the atmosphere-sea water interface. The systematic deployment of such geoengineering measures implies a new form of global governance that this writer does not believe attainable in a little less than fifty years.

Assuming no geoengineering approaches, the prime methods of dealing with climate change through most of this century will be the options already known to us. Some mix of renewables and efficiency gains, a revitalized nuclear option, and new benign ways of using the still remaining large resources of fossil fuels will be the main avenues. Despite some success, a large measure of adaptation to climate change appears inevitable.

SUPPORTING SECTIONS

The Complicated Case of Oil

The Difference between Discovery and Deployment Limited Sources for Oil

It is important to distinguish conventional oil production from that derived from non-conventional sources such as the oil sands so important to Canada. Conventional production—oil produced from wells without the need for special techniques—tends to be *discovery limited* in the sense that oil reserves found outside the OPEC group of nations are developed as soon as facilities can be installed. The cost of production of discovery-limited oil, including its transport to distant markets, is so low that in most cases it will find outlets almost regardless of economic conditions by displacing other sources of energy (including the more expensive non-conventional oil), during recessions. Only in rare cases, such as when the oil is found in very deep water or remote regions where transportation facilities cannot be justified at the time of discovery, is this not true.

Nevertheless, some countries in the Middle East will be exceptions to this rule for another decade or more for other reasons. Much of the already discovered oil is not yet being produced in these countries for reasons of policy. In the main example of Saudi Arabia, the reserves of conventional oil remaining are so large that the discovery of additional supply is of little immediate consequence. For this reason, it is difficult to assess potential of some of these countries including Iraq—there is general agreement there is much more conventional oil to be found but there is little incentive to invest in the exploratory drilling as long as this restrictive policy is followed. From the point of view of Saudi Arabia, premature drilling to prove reserves not scheduled to be produced for another decade or more may actually be disadvantageous because widespread knowledge that such oil has been discovered would lead to great diplomatic pressure to increase output to reduce prices. Conversely, however, production quotas negotiated in OPEC agreements are influenced by the size of the published reserves—in general, the higher the published reserves, the higher the agreed quota. Given these two opposing forces, OPEC members are faced with a balancing act to decide how big a reserve should be established in advance of production.

In contrast, the production of oil from non-conventional sources is *deployment limited*. Production derived from the oil sands of Alberta, from the heavy oil belt of Venezuela, from the large and relatively widespread resources of oil shales around the world perhaps in the future, and from such other options as the conversion of `stranded' natural gas reserves or coal to liquid fuels (South Africa converts both), are deployment limited in the sense that the location and nature of the starting deposits are not only known but, in the case of the oil sands at least, have been known for many decades. In such cases, production depends upon a decision to invest in the necessary facilities, not on making relatively unpredictable discoveries. Nevertheless, it is also true some production from conventional reservoirs may be classed as deployment-limited when this oil is found in deep water in difficult environments where both capital investment and technical risks are high: production from conventional reservoirs may not necessarily follow discovery automatically in this latter special case.

The risk to be faced in the production of oil from the various generally capital-intensive non-conventional sources is the possible sudden increase in output of low-cost oil from very large already discovered reservoirs in the Middle East. On a technical cost basis, oil from the giant reservoirs in the Middle East could be moved to Edmonton cheaper than synthetic oil could be produced locally from the nearby oil sands. For this reason, the deployment of facilities to produce non-conventional oil will be dependent in large measure upon the policy decisions of the OPEC group of nations before the peak in conventional oil production is reached. Nevertheless, one by one, more of the OPEC countries have reached, or will shortly reach, their maximum output. In another decade or so there may be only two or three countries left in the Gulf region of the Middle East capable of markedly increased conventional production. With such a small number of countries involved, there is the possibility that some form of agreement, or at least a tacit understanding, could be reached for the protection of non-conventional oil production elsewhere. The negotiation of a `Minimum Secure Price' was one of the very first priorities of the International Energy Agency when it was formed, and the time may be coming to revisit this subject.

This threat to costly non-conventional oil production is alleviated after the peak in world conventional oil production has passed. A reduction in the demand for oil due to a period of low economic growth or even as a consequence of measures introduced to limit the emissions of greenhouse gases is unlikely to be so great as to make the system as vulnerable to a sudden infusion of low-cost conventional oil from the two or three producers remaining still capable of doing so. Instead, the floor price will remain high because it will be set by the technical cost of the non-conventional facilities still operating in a period of reduced demand: the competition to supply the diminished market in a recession will be, in effect, among the various non-conventional sources, not with the few producers with limited volumes of additional cheap conventional oil supplies still available.[3]

Because the resources of coal are very large and fairly well distributed around the world, the conversion of coal to transportation liquids could, in principle at least, place an ultimate cap on the price of these fuels, but the deployment of such complex and expensive facilities is inherently difficult. Greenhouse gas emissions are also high in such synthetic oil processes. The one synthetic natural gas plant operating in the U.S. supplies captured carbon dioxide for enhanced oil recovery operations in Saskatchewan and it is possible the same approach could be used in oil-from-coal plants especially of the indirect liquefaction type as currently operated in South Africa.

The Effect of the Timing of the Peak in World Production of Conventional Oil

That the peak in world conventional oil production will occur before the peak in population is reached may be an accident of geology, but it is fundamental to an understanding of the future evolution of the energy system.

The issue for the energy economy is whether the price increase to be expected after the peak will be sufficient to induce a reduction in demand and encourage an increase in the supply of other sources of energy (including non-conventional oil) rapidly enough to maintain balance in the marketplace. Simply stated, given some success in the struggle against poverty around the globe, the problem is twofold in that (1) use of cars and other oil-dependent modes of transportation, especially air transport, may increase faster than the introduction and deployment of efficient vehicles (hybrids, fuel cell-equipped vehicles, etc.) can reduce oil consumption; and (2) some success in the fight against poverty on its own is also very likely to lead to a steadily increasing demand for fuel for transportation applications. Demand for such fuels grew steadily as living standards rose in such countries as Korea as it emerged from poverty, and this trend is now beginning in a much bigger market—China— and should be expected soon in India, if it has not already started. Greenhouse gas emissions will increase from the mobile transport sector of the economy for these two reasons.

A critical factor in evaluating the needs of the transportation sector as the peak in conventional oil is passed becomes the extent and the speed at which oil can be displaced from its present stationary markets. Though the gradual withdrawal of the relatively small consumption of oil from the generation of electricity will be relatively easy, it remains important to find other ways of generation especially in the emerging countries because demand for electricity must also rise to fight poverty. Withdrawal from the other stationary markets may be more difficult due to the great convenience of oil. Given some success with the withdrawal option, it is possible to delay the impact of the peak in the world production of conventional oil on the demands of the transportation sector by at least a decade or more.[5]

In summary, the need for the alleviation of poverty leads directly to an increased demand for transportation fuels and for more electrical generation. It would be difficult enough to deal with this situation without the simultaneous complications of the peak in oil production and the need to reduce greenhouse emissions. The gradual withdrawal of oil from its stationary applications may alleviate the effect of the peak on the transportation sector for a decade or more.

The World Natural Gas Dilemma

The large world endowment of conventional natural gas is at once both an opportunity and a danger. When gas is used to replace the other fossil fuels, emissions of carbon dioxide decline because of its lower carbon intensity. When it is used to supply incremental quantities of energy, emissions of greenhouse gases increase though not as fast as they would have if other fossil fuels had been used in its place. The possible escape of fugitive methane (21 times as potent a greenhouse gas as carbon dioxide) from an aggressive natural gas supply option is always a risk. It is now urgent that a strategy for the wise use of natural gas be devised throughout the world.

Natural gas is at an earlier stage of its exploration and development cycle than oil perhaps by as much as 25-30 years. The peak in world production of natural gas from conventional sources is not expected until about 2050 and possibly 10 or so years later. There are, however, two major complications. First, as time passes, the remaining resources will be increasingly located farther from conventional markets. There are three possibilities to deal with this problem: (1) very long and costly pipelines may be built to access Alaskan resources through Canada to Lower-48 American markets, to supply northern resources in Russia to Europe, and to supply Central Asian resources to China; (2) gas stranded beyond the range of pipelines may be converted to liquid form for shipment by cryogenic tanker as LNG; and (3) stranded gas may also be converted chemically to other liquids amenable to shipment by conventional tanker and useful for fuelling mobile applications. At such remote locations, the gas may also be consumed in local specially-built energy-intensive industries for the production of chemicals such as methanol (which may also be used as a transportation fuel), for the reduction of imported iron ore of high purity to supply a metallic iron input product for steelmaking in still other countries, and for the generation of the electricity required to produce metals such as aluminum on site. These latter applications assume access to deep water shipping sites on tidewater.

The second complication is that large quantities of natural gas exist and are still being found in the Middle East. These resources are so large that a repeat of the present dependence upon oil from that unstable region would seem inevitable at some time in the future without major energy policy changes.

The gas supply situation requires special attention in North America. The problem arises from the fundamental fact that in this region, the peak in production of natural gas from conventional sources will occur before the peak in world production of conventional oil is reached—this situation is the opposite of that for the world as a whole where the peak in conventional gas supply will come later. As far as Canada is concerned, the National Energy Board Supply/Demand study published in 2003 indicates conventional natural gas production from the Western Canada Sedimentary Basin, the main source of gas at present, will peak at least by 2004 in both boundary extreme scenarios studied by that agency.[6] There have been recent disappointments in the development of the Nova Scotia offshore gas industry. Nevertheless, Canadian production of gas from all sources—conventional and non-conventional—is foreseen as increasing by as much as one-third. This production is sufficient to meet domestic demand, if not all current exports, to at least 2025.

On this Continent at least, and possibly in such countries as China and India, efforts will be made to produce gas from more costly non-conventional sources (at first Coal Bed Methane [CBM], and later from other sources such as from `tight' formations and still later possibly from the very large resources of methane hydrates known to exist in the north and some off-shore regions). At the same time, increasing quantities of gas in liquid form (LNG) imported by specialized cryogenic tankers to coastal locations, including perhaps a new port in the lower St. Lawrence region, will augment the domestic conventional gas supply. The technical cost of the gas derived from the very dissimilar CBM and LNG sources will be comparable but the location of this non-conventional supply will be very different—the CBM will come from sources located mainly in the mid-Continent (although some supply is possible in the Atlantic Provinces) while, in contrast, the LNG will be delivered to sites on the coasts. Some mix of supply from these two different non-conventional sources will set the floor price for natural gas in North America when gas from conventional sources can no longer meet market demands.

A serious problem arises if the price of natural gas exceeds that of the distinctly different oil products with which it competes. It is not easy for homeowners to convert to fuel oil (it would be a switch back in many cases) but industrial users will surely substitute where they can. The simplest case is the re-conversion of the older power stations originally designed to burn heavy fuel oil but were subsequently changed to natural gas-firing. Some have retained full dual-firing capability and hence heavy oil may be substituted in a very short time. In the more likely case, some generating stations still retain the vestiges of their former oil storage and firing equipment and so a re-conversion might be possible in a year or so.

The problem is the most acute with new combined-cycle electrical generating facilities, the favoured option for additional electrical generation at present. The competing liquid fuel in this case is not heavy fuel oil but essentially the same refined liquid that is consumed in the turbines of the aviation industry. Because deregulated electrical networks are subject to price peaking, combined-cycle plants can outbid other consumers of natural gas or liquid turbine fuel, at least over the shorter-term. Given such price `spiking', independent generators of electrical energy can pass through their increased costs much more easily than can other industries. This situation arises because the most expensive electricity to consumers is what cannot be supplied in curtailments: meeting the electrical generation requirement will always take precedence in a deregulated market.

There is the complicating issue to whether environmental standards can still be met on back conversion of turbines from gas to liquid fuels. In the case of combined-cycle technology, the problem centres around NOX emissions in sensitive regions as it is not clear that the very low emissions now being obtained in some advanced turbines fired with natural gas can be met with replacement liquid fuels. This requirement would likely be waived in emergency situations.

This crossover problem leads to a major policy dilemma for policy makers. The extent to which natural gas should be relied upon for the generation of electricity in North America is an outstanding issue. Apart from the purely energy policy aspects, there is the possibility the aviation industry would be further undermined at a time when it has been weakened by both terrorist attacks and economic downturn. It is thus critical to understand the consequences of the interplay between the peak in world production of conventional oil with its attendant higher oil prices, and the peak for conventional gas production on this continent.

The increased need for LNG tankers is an opportunity for Canada in another field. The large requirements for cryogenic materials—aluminum and nickel (for stainless steel)—required to build these tankers and the allied shipping and receiving facilities will provide an additional important market for these metals of significance to the Canadian economy.

What About Coal?

The world resources of coal are large and better distributed than those of the other two fossil fuels. An increasing coal supply would be possible for about a hundred years on a world basis. There is, however, a major caveat in the assessment of coal resources. If people do not want the surface of the land disturbed for surface mining or do not want to work underground in an inherently dangerous and dirty occupation, the effective available reserves may not be so great. It is possible, however, that current advances in robotic mining techniques may reduce the need for people underground and at the same time improve safety.

The problem for increased coal consumption is its impact on the environment, both real and perceived. With the present state of technology, it is possible to reduce all emissions released in the generation of electricity to acceptable values with the exception of carbon dioxide by employing such emerging technologies as the Integrated Gasification Combined Cycle (IGCC).

In the future, carbon dioxide may be captured and sequestered employing technologies that will soon reach maturity. There are two aspects of this possibility. Capture and sequestering will always be expensive in terms of both extra investment and higher operating costs, including increased fuel consumption per unit of electrical output. It is paradoxical that to reduce carbon dioxide emissions, it may be necessary to use more coal per unit of useful output. Also, due to their greater technical complexity, individual facilities will have to be large to minimize their capital needs and operating costs on a unit basis. The acceptable sites will be limited to locations where the coal inputs may be readily assembled and where the distance to the carbon dioxide sequestering facility, whether disposal is in the oceans, in aquifers, or for application to enhanced oil recovery operations in the oil industry, is not excessive. The Canadian Clean Power Coalition, whose membership includes the operators of about 90% of the present coal-burning electrical capacity in the country, has been formed to identify and develop the technological options relevant to Canada. The aim is to install capture equipment on an existing facility by 2007, and of developing a prototype installation employing new advanced technology by 2010.

The economic imperative for large scale facilities suggests the favoured option in the long run, if coal is to be used extensively at all, would be the construction of `coalplexes.' Typically, coal would be gasified with oxygen and the resultant gas, after processing and purification, would be used to generate electricity, and also be processed to produce hydrogen and liquid fuels. Because the cost of the sequestering operation, including its associated carbon dioxide pipeline, is scale-dependent, it is possible other industries that could capture carbon dioxide will locate nearby. Such industries might take electricity, hydrogen or other fuels as needed from the coalplex, and send back carbon dioxide captured from their operations for blending with that arising from the coalplex before dispatch to the subsequent sequestering operation. These facilities, with their industrial satellites, could possibly be built at some tidewater locations.

[*Note Added in April 2003*: The U.S. Department of Energy has announced it will support one half the cost of a $1 billion venture to build a coal to electricity and hy drogen plant with virtual total elimination of emissions (including most of the carbon dioxide) to be known as *FutureGen*. A consortium will be organized to manage the program which calls for the design and construction of a 275 MWe facility over the first five years and test operation for another five. It is envisioned the facility will be a test bed for the demonstration of new technologies in this field.]

It is an important issue to compare the cost of electrical energy derived from coal including the additional steps required for the capture and sequestering of carbon dioxide with the new advanced nuclear power options. At the time of writing, the costs of these two very different approaches appear to be roughly comparable. It is ironic that both coal and nuclear options have problems with the public acceptability of their respective disposal problems: people may be faced with the choice between radioactive waste storage in stable geological formations versus disposal of captured carbon dioxide in saline aquifers or the deep oceans. Only the wind and solar options are relatively free of such public concerns.

The coalplex option has the advantage of offering other products such as hydrogen and liquid fuels along with the electricity generated. The cost of hydrocarbon liquid fuels produced in such facilities could, in principle, cap the international price of oil if such facilities could be built sufficiently fast. The nuclear option can only supply liquid transportation fuels by the decomposition of water, usually by electrolysis. However, there may well be an indirect approach where steam and perhaps hydrogen produced from nuclear sources is used in the recovery and upgrading of bitumen from the oil sands of Alberta.

Except for the indirect effects of inflation, all four options for the generation of electricity–coalplex, nuclear, wind and solar—are relatively independent of price increases related to the peak in the world production of conventional oil. Coal resources are sufficiently large and the mining industry sufficiently dispersed that prices are set mainly by interna competition from different sources around the world; known uranium resources can easily meet the present demand from the nuclear power industry (Canada is the largest producer); and the other two options do not use a consumable fuel source. All four may be deployed simultaneously depending upon local conditions.

The Threat of War in the Middle East

At the time of writing, there is the threat of war in the Middle East following the passage of the United Nations Resolution on 8 November 2002. All wars in this region, regardless of their original cause, tend to become oil wars and this one will likely be no exception. (It is interesting that the controversy over nuclear operations in North Korea may be due to the need for more electricity in that nation. This difficult international situation may also turn out to be strongly energy related.)

Two arrangements of long standing may well be overturned by this impending military action with imponderable long-term consequences. The first of these revolves around the unusual pattern of the supply of world oil. Very low-cost production from large reservoirs is withheld from world markets by OPEC policies to support the international price. This arrangement is only possible to the extent the OPEC nations remain a coherent group led by Saudi Arabia and its close allies. Though this price support system may be expected to break down as unnecessary as the world approaches the peak in conventional production, a premature ending of this unstable supply pattern would complicate matters greatly at this time.

It is difficult to predict the price of oil as the previous controlled system starts to disintegrate, but once it does start to fall, there are reasons to believe it will continue downwards to low levels. During the initial period of hostilities, the price on the New York oil trading market may increase at first due to uncertainty to the $US 30s range (thirty-day rolling average) but fall slowly afterwards possibly as low as the $US10-14/barrel range. (For another view of the possible price movements due to the war see Nordhaus.[7]) In Canada, a price drop on international markets of this magnitude in the next year or so would seriously impair the speed of development of the oil sands industry in Alberta and of offshore production in Atlantic Canada. In the U.S., possibly as much as one million barrels of day of output might be lost from mature high-cost low-production wells as they are shut-in. The exploitation of the expensive deep resources of the Gulf of Mexico would also be slowed.

In the longer term, the sudden ending of the second unstated and informal understanding in the Middle East may prove to be more serious. Saudi Arabia and its close Gulf allies provide funds for Islamic organizations around the world in part to fulfill their obligations to Almsgiving, one of the five pillars of Islam. The donors do not specify too closely where this money ends up and some no doubt finds its way into the hands of terrorist or revolutionary organizations. In return, up to now, there has been a tacit understanding that the oil production facilities of the region would not be attacked. Remarkably, this informal arrangement has held sway for the last three or four decades though incidents have been reported in such countries as Algeria. No doubt there have been some unreported attacks in other countries in the region. Despite the acute political tensions in this unstable part of the world, nothing like the present guerrilla war in Columbia has occurred, where pipelines are blown-up quite regularly, or has been the case in Nigeria. The first assault on a tanker at sea was widely reported in late 2002 and a refinery in Assam in India came under attack in an unrelated conflict in 2003. However, the long strike in Venezuela in early 2003 did not lead to serious damage to facilities in that country.

This situation may be expected to change if there is western military action in the Middle East and ownership or control of the Iraqi oil fields is seen to have come under Western influence. The oil facilities may be expected to come under some level of guerrilla attack throughout the region and in possibly some non-Islamic oil producers as well.

To assess their vulnerability to attack, it is convenient to consider the oil production facilities as divided into two broad categories—the intensive and the extensive. The intensive or concentrated facilities consist of the storage and refining facilities together with the tanker loading docks. The extensive facilities consist of the individual production and gathering facilities spread over wide areas in the field. Different defensive strategies are required for these two cases. Because it is difficult to defend against many small insurgent attacks on the extensive facilities spread over a wide area, they will be the prime target and hence this class of action may be expected to be the main threat. Nevertheless, attackers may also be expected to lob occasional rockets, etc., into the most vulnerable intensive facilities as a diversionary tactic. The fires ignited in outlying tank farms result in good television with flames reaching high into the night sky though the damage may not be of great significance. The main objective of this type of peripheral attack on the intensive facilities would be to pin down as many of the defending forces as possible to guard these central facilities to make it more difficult to fight the long-term continuing war of attrition on the widespread wells and pipelines. A main aim of the terrorists might be to disrupt loading schedules for tankers to make refinery operations in consumer nations troublesome.

The defence may concentrate on such new techniques as surveillance by drone aircraft equipped for night vision to detect raiding parties. However fought, a difficult situation results especially with the world expected to become steadily more dependent upon supplies from the Middle East over the next decades.

The energy picture will become a confused one before the peak in world conventional oil production is reached given a deep `V' in prices in the intervening period. This prospect becomes more probable with a war in Iraq. The possibility of a long drawn-out guerrilla war with periodic attacks on the producing facilities of the Middle East will not make it any less so especially as world reliance on that region increases.

Dematerialization and Electricity

The situation is also complicated on the demand side by the tendency of the economy to dematerialize as opposed to straight forward continuing gains in the efficiency with which energy is consumed. The knowledge economy is surely different from the older physical economy based mainly upon things. The ratio of primary energy consumption to GDP has been falling steadily over the years: the difference in the decline in this ratio over what can be attributed to price changes is usually termed `Autonomous Energy Efficiency Index' (AEEI) in the economic literature. By this is meant the decline in energy requirement per unit of GDP not accounted for by increases in price. Nevertheless, some authors take the view that the slow but nearly continuous reduction in this ratio experienced over the year is in part illusory. They claim that when the quality of the energy demanded is taken into account, there is effectively little or no decline.[8]

The apparent fall in the primary energy/GDP ratio unfortunately conflates two distinctly different trends in the energy economy: the steady, if slow, autonomous gains in efficiency on the one hand and the gradual dematerialization of the economy on the other. Gains in efficiency are essentially just that: less energy is required over time to perform the same energy services due to the steady, if unspectacular, advances in technology that occur regardless of price changes. These improvements on the demand side are often asymmetrical: improved insulation is not removed from houses and other structures were the price of energy to fall.

In contrast, the dematerialization process reflects the gradual change in the basic structure of the economy as intellectual activities become more important relative to economic activities revolving around the supply of material goods. A small silicon chip carrying the same circuitry is generally more valuable than a larger one.

It is very difficult to distinguish between these conceptually very different processes. Moreover, a dematerializing society, if one does in fact exist, is a paradoxical one. Deep questions arise about such things as the nature of work including some prosaic issues about the definition of the hours of work or where it is carried out (Can one really stop thinking about one's intellectual projects even on holiday?). In contrast, the progress of simple efficiency improvements, in the sense of doing existing things ever better or faster or cheaper, can be projected or foreseen with at least some confidence. The ultimate output of an essentially intellectual process can only be guessed. It is much more difficult to estimate how fast dematerialization will proceed and how far it will proceed.

A dematerializing society may still need electricity to power its computers and for information processing techniques in general. Thus, in the developed world, one might expect the demand for electricity to remain strongly linked to changes in GDP, though the demand for other forms of energy would fall even when such questions as to what extent techniques devised to measure GDP in a classical economy are applicable to a dematerializing society.

From the point of view of the long-term control of the emissions of greenhouse gases, it is electrical generation that should be the focus of attention in a dematerializing society. Such a society would also place a premium on the reliability of the electrical supply—blackouts especially of the kind that afflicted California for a time would be very undesirable. Nevertheless, an attempt to distinguish the dematerialization phenomena from simple gains in efficiency using world electrical generation as a proxy for world GDP was inconclusive.[9]

The Importance of Hydrogen Vehicles in the Longer-Term

There is no other energy source or `attracter' available that will lead the world away from oil of its own accord nor is there one on the horizon. This is because the technical cost of producing conventional oil is so low. All other sources, especially those that are environmentally benign, are generally more costly. We have seen that the introduction of other supplies of energy before the peak in conventional oil is reached merely results in the price of oil declining and that it has a long way to fall before world output would be affected greatly. It remains to be seen if the intended introduction of hydrogen-powered vehicles in significant numbers after 2010 will be a factor in the determination of oil prices before the peak. It may be that the introduction of hybrid vehicles will be sufficient to meet both oil savings and environmental objectives in the next decade or so. After the peak, the situation is less complicated in that the minimum price is set by the least cost alternative to oil. It is then that a successful hydrogen fuel cell option for vehicles becomes important for the long term.

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