Energy Elements

A Retrospective from Past Papers

John H. Walsh

Energy Advisor

No country has a more complex energy system than Canada. With the possible exception of the intensive solar option open to the desert countries, it has every choice on the supply side and engages in every activity on the demand side. The many choices extend to those not yet perfected such as the recovery of methane from the large resources of frozen hydrate clathrates known to exist either on land or under the sea to generating electricity from ocean currents. Canada is a physically large and cold nation whose industrial activities by their very nature will always be energy intensive. It is a major energy trading nation that also provides transportation corridors to its large neighbour. This plethora of choices is further complicated by the pronounced regional differences in the country – from an energy point of view it is difficult to find two jurisdictions as unlike as Alberta and Ontario. The many choices and opportunities open to Canadians tend to induce policy paralysis. There is, however, one major difference between the demand and the supply side. Canada shares with other countries the need to develop the technologies required to consume energy with greater efficiency: in contrast, its supply options tend to be, if not unique as in the case of the oil sands, more often than not specific to the nation. Canada thus shares the need for better conservation technologies with others, but its supply options often require distinctive and individual action. For this reason, this paper is concerned primarily with illuminating the situation in which the nation must act for itself and thus does not emphasize the many and important issues on the demand side it shares with others. Perhaps because of this complexity arising from the many options open to it, Canadians tend to have a poor if not actually a mistaken grasp of the fundamentals of the energy economy. The explaination and successsful communication of the situation in which Canadians find themselves in the energy field is a major task not yet fully accomplished.

If there is one unifying thread common to the energy economy as a whole, it is its vast size and complexity. The fossil fuels, which accounted for 87.7% of the total primary supply in 2005 (biomass excluded), still dominate. It is inevitable that such a large and intricate system will have a high inertia: the world energy economy may be thought of as a huge super tanker ploughing through the waves of the sea at considerable speed but one incapable of a rapid change in course. The three fossil fuels may be distinguished by their physical form as solid (coal), liquid (oil) and gas (natural gas). The implications arising from these differences in state are seldom drawn even for such an apparently mundane matter as storage. The stockage of coal is, for all intents and purposes, infinitely elastic because it may piled on the open ground though some precautions must be taken (Canadians are expert in this practice because of the annual closure of navigation on the Great Lakes.) Crude oil and its main products are liquids that must be stored in tanks or in underground storage chambers of one kind or another. The building of these tanks is costly and time-consuming. Hence, when storage is full, oil production or refining must be curtailed and tankers delayed by ‘slow-steaming’ on the oceans. Natural gas is the most difficult and least flexible of the three fuels to hold in inventory. Storage is limited to charging depleted reservoirs under pressure or to the expensive cryogenic conversion of the gas to a liquid for holding in well insulated tanks. When these special facilities are full, delivery must stop and the price usually falls suddenly and significantly. Nevertheless, the problem of storing the fossil fuels is much less than in the case of the electrical system where there is still effectively no inventory at all. Since electrical generation is the major outlet for coal and an increasingly important market for natural gas, the fact that coal may be more easily stored than gas is an important advantage in maintaining stability in electrical networks.

The production of the fossil fuels in Canada is mainly centred in Alberta. When large economic rents arise from exploiting reserves of conventional oil and natural gas especially during periods of high energy prices, the fiscal management of the country has been difficult. However in recent years, there has been has been some tendency for more geographic dispersion in the domestic supply of oil and gas. Significant quantities of oil are now produced in Newfoundland waters and natural gas from off-shore Nova Scotia. There are prospects for more natural gas from the far northern arctic regions in the near future and for more oil and other liquids from these regions later on. The production of conventional oil in Alberta is now past its peak and the production of conventional natural gas may peak in a year or two with the result that the two major sources of economic rent may soon be declining in that Province. The production from the oil sands (though not necessarily the associated upgrading processes) will always be located in Alberta (although some limited production may be possible in Saskatchewan) but the economic rent from this activity, though high at present, is less than in the case of conventional oil. Most uranium production is likely to continue to be located in Saskatchewan. New centralized hydroelectric generation is now limited mainly to the few large undeveloped sites remaining in Newfoundland, Quebec and Manitoba. Coal resources in the west are large but their exploitation gives rise to little economic rent. The opportunities for the renewable sources are more widely spread across the country. Despite these ameliorating factors, periods of high oil and natural gas prices will continue to stress the Canadian federation in one way (revenue concentrated in Alberta) as will the need to reduce emissions of carbon dioxide from the fossil fuels in another (opportunity denied in Alberta).

Oil will always dominate the energy system because of its three special attributes.

- Almost all energy needs can be met directly or indirectly with oil and its products. It is difficult to think of a specific energy requirement that could not be met with oil one way or another.
- As liquids of high energy density, oil and its main products may be transported long distances at low cost either by tanker on the seas or by pipeline on land. The practical effect is that the price of energy contained in oil - free of taxes – can be nearly the same everywhere. The contrast with the other fossil fuels is striking. Coal is expensive to move on land even when dedicated unit trains are used on the railways though it is not costly to move long distances by sea in large colliers. Energy in the form of natural gas is some four-to-five times more costly to move than oil by overland pipeline, and is even more costly to ship in the form of Liquefied Natural Gas (LNG) in special cryogenic tankers.
- Oil is sold on world markets on an inverse price basis – during periods of surplus, low-cost oil supplies are frequently shut-in the Middle East though more expensive sources continue in production elsewhere. With the possible exception of diamonds and a few other special but minor cases, this inherently unstable situation is unique. Nowhere is this more striking than in case of the oil sands of Alberta where expensive oil production tends to continue during periods of slack demand while low cost sources in the Middle East are withdrawn from the market. This effect is so strong that the average overall technical cost of production can actually fall at times during recovery periods as production of Middle East crude increases relative to the higher cost production elsewhere.

Two important consequences arise from these attributes:

- The owners or controllers of oil may supply any fraction of the entire energy market (not just oil) at any time and at any place by simply reducing their price; and
- Those developing alternatives to oil (whether on the supply or the demand side) are confronted with a competitor whose price could fall significantly at any time. Because of the large economic rents involved in the production of most conventional oil, there is a long way for the price to fall before there is a major reduction in its supply. This inverse price

> supply pattern can apply any time before the peak in conventional oil production is reached but once it is passed, the price tends to be supported at a higher level by the next least costly alternative.

It follows that before the peak in world conventional oil production is reached, oil can enter the energy system easily but can only be replaced with difficulty. This fundamental asymmetry is at the heart of the problem of displacing oil with other options whether on the supply or the demand side and represents a major obstacle inhibiting the reduction of emissions of carbon dioxide.

It is widely held that very little about oil can be predicted with certainty, especially its price. Yet for the past twenty-three years, world per capita oil consumption has been effectively constant at about 4.51 barrels per person despite wide swings in price, major changes in economic conditions, and even local wars during the intervening period. Few things in the energy economy have been more predictable. Furthermore, world per capita consumption shows no great signs of deviating from this trend in the near future. Because oil seldom 'lives' on the earth's surface for longer than a few months before its consumption (only rarely more than a year), the inventory does not change greatly from year-to-year because there is sufficient time available to make adjustments to match prevailing market requirements. The consequence is that world per capita oil production measured on a yearly basis approaches the same degree of constancy as its consumption. (One other such predictable relationship occurs in the electrical system, where with rare exceptions, such as in Pennsylvania at the time of crisis in its coal and steel industries or recently in Ontario during a period of benign weather, electrical consumption rarely declines in absolute terms.)

The reason for this great predictability in world oil consumption is not completely clear. The most probable explanation is that oil is consumed by two quite different groups of people around the world: the smaller number of rich people (a little over one billion) consume a great deal of oil per capita whereas the greater number of poor people (about 5.5 billion) consume very little. The per capita consumption by the rich group may be falling under the influence of higher prices, a maturing industrial structure, and advances in technology as the world enters the information age whereas that by the poor group may continue to grow because only now are the latter entering the oil and industrial ages. The developing nations need to consume a certain minimum quantity of oil almost regardless of price. China and India are the leading examples at present with large numbers of vehicles suddenly coming into service. These two opposing tendencies may result in this rough balance. Given present population trends, if this empirical relationship continues to hold, the growth in the long-term consumption of oil may be estimated at a little less than an annualized one million barrels per day or somewhat lower than most present published estimates of future demand. Nevertheless, the requirements of the three large rapidly developing countries – Brazil, China and India – remain a wild card in the future demand for oil.

Oil constitutes the most important commodity in world trade followed next by a psychoactive agricultural foodstuff, coffee beans. Oil concerns all nations one way or another. The inverse price pattern of supply becomes less important when demand is high and when all effective capacity is effectively utilized as it was during much of 2005 and 2006. When there is a return to significant idle capacity, usually in the OPEC nations as may well occur in 2007, the system has so far tended to revert to the unstable inverse pattern of supply rather than adopt a more rational rising supply curve. Such an unstable price regime could invert to a stable progressive cost pattern at any time where the lowest cost oil is produced first, but despite many predictions of inherent instability, this has not happened for several decades.

Oil accounted for 42% of the emissions of carbon dioxide from the fossil fuels in 2005. The transportation industry relies upon oil for 90% or more of its energy needs and in most developed countries, the needs of this sector approach some 70% of the total oil consumption. Given that 90% (or a little more) of the individual trips taken in cars and light vehicles are less than 50 kilometres in length, these four statistics taken together strongly suggest that the best option available to deal jointly with the problem of peak oil and the reduction of greenhouse gas emissions is the development of a workable plug-in hybrid car. This approach is supported by the current successes in improving batteries, particularly those of the lithium ion type. There is the further advantage that turning to electricity to meet a greater share of the energy needs for transportation is unlikely to attract road taxes in the early years before this class of vehicle becomes ubiquitous. This absence of tax provides a *de facto* major economic driving force automatically without the need to implement explicit policy changes. In this option, more of the energy needs of the transportation sector gradually become an additional loading on the electrical network. In the early years when this new requirement is small, the electrical system can meet this additional demand by incremental expansion in the normal way but later, when there are many cars and other light vehicles powered in part by electricity, careful consideration will be required as to how this large new electrical load may be generated and delivered. The inflexibility of nuclear power generation and the intermittent character of most renewable options, such as power derived from the wind, are major complicating factors. The production of hydrogen for use in a later generation of vehicles equipped with fuel cells (and for other purposes) could keep the grid in balance. There may be good reason to produce the hydrogen in two quite different ways at the same time: by the electrolysis of water in off-peak periods and by the gasification of coal in facilities equipped for the *shifting* of carbon monoxide with steam to hydrogen and carbon dioxide. The greenhouse has to be separated in any case and could be captured for sequestering. In the latter process, the hydrogen produced from coal would be directed to electrical generation at peak periods in gas turbines operated in combined-cycle mode, and allocated to power vehicles and for other uses off-peak. This combination of electrolysis and gasification technologies – one producing hydrogen off-peak and the other producing hydrogen as a fuel for electrical generation on peak - provides a double set of tools to balance the grid in a future with a significant additinal loading from transportation requirements when carbon dioxide emissions must be constrained. This option depends, however, upon the early adoption of hybrid plug-in vehicles and a later successful transition to hydrogen-based fuel cells as a major source of power in the automotive sector of the economy.

There is nothing new in passing peaks in the world energy system. The peak in world per capita oil consumption was reached as early as 1973. Canada (1973) and the U.S. (1971) have both passed their peaks in conventional oil production, and Norway (2001) and the United Kingdom (1999) have reached this stage of maturity in the last few years. Mexico is approaching it now. The immediate future of the world's energy system can be thought of in terms of the interplay of the sequence of three forthcoming peaks - the peak in North American production of conventional natural gas is expected before the peak in world conventional oil production which in turn will be prior to the peak in world conventional natural gas production outside North America. This marked division in the prospects for conventional natural gas supply between North America and the rest of the world taken together explains the great interest in shipping liquefied natural gas (LNG) especially to the U.S. but this option affects Canada as well. Seven ports to receive this new fuel have been announced for various locations in Canada of which five are in eastern Canada and two are in British Columbia. These facilities aim at taking advantage of the superior deep water reception sites in this country although the main object is re-shipment of the reconstituted gas to the U.S. by pipeline. Thus in yet another instance, Canadian energy prospects have been heavily influenced by the near-by presence of the U.S. This characteristic interdependence is particularly strong in the case of natural gas for a simple reason: the capacity of a pipeline increases essentially according to the square of its diameter but the unit capital and operating costs decline with carrying capacity. It was difficult to justify the building of an efficient pipeline in B.C. to bring natural gas from discoveries in the northeast of that Province to its limited lower mainland market some fifty years ago. Only by serving an additional market in the Pacific North-West of the U.S. was it possible to lower unit transportation costs sufficiently to justify the line. This 'piggy-back' aspect applies to the still unresolved pipeline proposals to move gas from both Alaska and from the Canadian arctic regions to southern markets. Similarly, building large and efficient ports here to receive LNG from other countries destined for U.S. markets makes this gas available to Canadians as well on terms less costly than it would be otherwise.

World conventional natural gas resources are so large that the peak is not likely until after 2030, perhaps as late as 2050. Both owners and exporting countries will be actively seeking outlets over the next decades especially for the case of gas stranded beyond the pipeline range of markets in some countries but with access to the seas. Shipment in the form of LNG is not the only option. Other possibilities include the conversion of this gas to methanol or to other liquid transportation fuels for shipment by tanker as planned in Qatar and elsewhere, or local consumption in energy-intensive industries built to serve world markets such as smelting aluminum or producing directly-reduced iron for the steel industry. Despite these other possibilities, LNG will predominate and, because of the many potential players in a number of supplying countries, there is a good chance that a more-or-less competitive trading market will emerge though present shipments are nearly always supplied under long-term negotiated contracts. If such a market develops under something approaching equilibrium economic conditions, natural gas provided in this way could be delivered from North American reception facilities for about $US 4.00 per million BTU to distribution pipelines. This competitive price poses a major concern for those planning a new generation of nuclear reactors. With the advances in combined-cycle gas turbine technology, electricity generated from natural gas would be competitive with that generated in up-dated nuclear facilities at a price in the region of $US 5.00 per million BTU. Nevertheless, only with the rare combination of a severe economic recession, moderate weather conditions (neither too hot or too cold), and good domestic exploration results for natural gas at the time is it probable that such a low equilibrium price will be approached in practice. The actual price will no doubt be higher due to the difficulties and delays involved in the siting and construction of the LNG receiving stations, For this reason, these facilities are unlikely to be built fast enough to satisfy the North American market as the peak in conventional gas production passes. This is true even with the concurrent expansion of the coalbed methane (CBM) industry because the technical costs of this non-conventional production approximate those of the LNG supply. Moreover, the geographical location of the CBM supply is very different from those of the LNG receiving ports.

Those proposing new nuclear facilities are faced with a major quandary because electricity produced from gas at its theoretically possible equilibrium price may be cheaper than from the newest nuclear options but more costly at the actual likely non-equilibrium price. The situation is further complicated by the need to control emissions of carbon dioxide but this requirement may not be applied to natural-gas fired generation in view of its other environmental advantages. The immediate future for nuclear generation may thus be dependent upon factors difficult to quantify and very uncertain in timing.

Conventional supplies of oil may be distinguished from their non-conventional counterparts because they arise in two fundamentally different ways: the supply derived from conventional sources is limited by the process of *discovery* while that from non-conventional sources is limited by the quite different process of *deployment*. It is useful to further distinguish between these two modes of production by introducing an additional test of a time lapse of ten years. Given the considerable economic driving force due to the current high prices, if a source of oil is not brought into production a decade after its discovery, it should be classed as non-conventional. This is because some further obstacle is restraining its development whether it be its heavy chemical structure, its awkward occurrence whether in water of great depth or in severe or remote Arctic locations, or by the effect of political and administrative barriers of one kind or another. European explorers knew of the oil sands of Alberta in the eighteenth century and the aboriginal peoples long before that. The production of such non-conventional oil depends upon developing the appropriate technology, marshalling the usually much higher unit capital requirements, or overcoming the obstacles arising from great depth, adverse location, severe climate, etc. Such sources may be contrasted with the production of conventional oil whose output depends more upon how much is found than any other single factor. In the conventional case, the peak production usually tends to track the discovery process with a time lag typically from 20 to 30 years.

Of the three factors involved in determining the track of the world conventional oil system over time – new production coming on stream, increases in consumption, and the depletion occurring in the pre-existing production facilities – it is the latter quantity that is most uncertain. The future production of oil supplies from new sources in the near term (certainly over the next five years and perhaps up to ten) may be predicted with considerable accuracy by the simple summary of new projects scheduled and announced by the industry around the globe. Such a production profile may be adjusted by judgement for the slippage common for such major undertakings. As far as changes in consumption are concerned, oil usage has been shown to be virtually constant on a per capita basis for nearly the last quarter century. Less is known about depletion including its simple definition. To clarify the situation, the important work of Skrebowski in this field is extended by the introduction of two new terms. The Effective New Production (ENP) quantifies the additional oil to be expected in the near term resulting from the start of production in known new fields. A second term, the Net Depletion (ND) is defined to embrace the overall yearly decline in the pre-existing production facilities. Given these definitions, the ENP can only be a positive number whereas the ND may be either positive or negative. This is because the ND term includes not only the summed depletion from individual wells in the older fields but also the gains arising from such post-discovery measures that may be undertaken to sustain production in the pre-existing fields as the adoption of enhanced oil recovery techniques and additional production from infill wells in these fields, including those drilled horizontally. With these quantities defined in this way, the change in production in any one year as compared to the one before is determined by the difference between only two terms, (ENP – ND). This value may be compared with the change in production reported in the published historical statistics. World production in 2005 increased an annualized 900,000 barrels per day over 2004. Given that the ENP was between 2 and 3 million barrels per day that year, the indicated world Net Depletion in 2005 can then be estimated as between 1.1 and 2.1 million barrels per day given the assumption of a negligible change in idle capacity between these years. Much of this loss occurred in three large offshore producers - Norway, Mexico and the U.K.

A peak or a plateau in oil production results when ENP equals ND. When the ENP – ND term is less than the gain in consumption in a given year, balance can only be achieved by a reduction in inventory, by bringing pre-existing idle capacity back in production, or by developing non-conventional sources of oil. The ENP quantity is essentially inflexible in the short term given that it is determined by decisions taken in the past and fixed by the long time needed to construct and commission new facilities. In contrast, consumption may react more quickly to changes in economic conditions. With a sudden increase in demand, the system may reach a stage when balance can only be achieved through the process of demand destruction induced by strongly higher oil prices.

When the peak is passed in an individual oil field or a producing province, it is common practice to express the decline as a given percentage per year in a range that normally falls between 3-7% though figures as high as 9% have been reported for the North Sea as a whole in 2007. A constant percentage over time implies that the production will decline more slowly in each subsequent year when expressed in absolute quantities. For the world as a whole, however, the reverse is almost certainly true in the period immediately following the passage of the peak. World production is more likely to approach a spread-out plateau-like peak with only a small absolute decline each year at first that increases steadily as the years go by. These declines may be so small at first that the exact timing of the passage of the peak is only certain in retrospect. Later, when depletion is further advanced, the absolute output of oil from conventional sources will fall less in each subsequent year. Thus there must be a change in mode in the world decline curve at some specific time later in the depletion cycle. The date of this transition from a steadily greater fall in production each year to a logistic-like function characterized by a slowly declining 'tail' is surely the next important event in the world production of conventional oil to be expected after the peak is passed.

Before the peak, there is no special reason for the price of oil to be at any particular level: supply/demand conditions at the time will be the most important determining factor. Only the higher prices anticipated as the peak is approached will place upward pressure on current levels independently of the immediate supply/demand balance. At the usual discount rates, this effect is unlikely to be significant until some five to eight years (ten at the most) before the peak is reached. Without this discounting effect, the price may be expected to 'hunt' unpredictably up and down as the peak is approached on normal systems engineering grounds. After the peak is passed, the situation becomes very different and, provided there is at least some approach to equilibrium market conditions in a possibly chaotic situation, the price will be supported by the least costly alternative of any significant size on either the supply or the demand side. These other options are presently much more costly than the average technical cost of production of the remaining conventional oil though it is true these latter costs are now also starting to rise appreciably at margin. Though the price of oil will be considerably higher after the peak, it is also likely to be more stable and less erratic.

The problem of dealing with excessive carbon dioxide emissions from the fossil fuels was underestimated initially because of two previous related successes in dealing with atmospheric problems. It proved surprisingly easy to conclude an international agreement to deal with a somewhat similar global problem, the need to reduce emissions of the chlorofluorocarbons to mitigate the destruction of ozone in the upper atmosphere (the CFCs were first produced synthetically for application to mechanical refrigeration in the 1920s). The reasons for this early success include: the number of manufacturers worldwide was not large, the quantities of the chemicals involved were manageable in size, and suitable substitutes were rapidly found. Special provisions were readily agreed to prevent the cost burden falling excessively on developing countries. A second success, this time regional in character, involved the reduction of the deleterious effects of acid rain due mainly to excessive emissions of sulphur dioxide from coal-fired power stations and from the non-ferrous smelting industries. Though more difficult to achieve, the introduction of an emissions trading system led quickly to a market-based cost discovery process: the additional burden of either installing sulphur capture systems or switching to coals of lower sulphur content was soon found to be manageable. The good results obtained gave rise to the belief that such economic instruments would be useful in dealing with carbon dioxide emissions.

Given these two previous successful examples, there was reason to believe at least initially that the problem of climate change would also be tractable using the same techniques. Unfortunately, this proved not to be the case. There were three major differences that made the situation much more difficult in the case of carbon dioxide: the scale of the emissions was very much greater; the number of industries affected was very large (in fact, all in the broadest sense that energy affects everything); and there were special problems arising from the unique attributes of oil. As far as scale was concerned, the quantities emitted were either huge by very large and well-established industrial point sources in almost all countries or nearly as large emissions from a myriad of small point sources, mostly mobile. The problem touched every country, every home, most industries, and was particularly important to the transportation sector where it affected everything from privately owned cars to major airlines, railways and companies shipping by road or sea. The situation was further complicated in that one of the most rational economic instruments available – a tax on carbon emissions – has been politically impossible to apply in most countries largely because the problem touched everybody so everyone had to pay.

The unique attributes of oil are also involved because of the large economic rents that arise in the production of conventional oil. The introduction of any substitute for the fossil fuels faces the prospect of competition from lower prices for oil whether they act on the supply or the demand side: oil prices can fall a long way before production from conventional sources will be greatly reduced. Because the economic incentive to use conventional oil is so large and its utility so great, it is probable most such oil will be consumed one way or another regardless of what policy options are eventually adopted to reduce emissions. The only real prospect for the reduction of carbon dioxide arising from conventional sources of oil is to delay its production in one way or another. The intractability of this problem proves another example of the fact that oil is much easier to introduce into an energy system than it is to remove. It is this asymmetry reinforced by the ever present potential fall in the price of oil that makes the problem of dealing with carbon dioxide emissions so difficult. Nevertheless, the lessons learned in the somewhat surprisingly successful international negotiations concluded to control the CFCs and the application of economic instruments to deal with the acid rain problem have provided useful precedents.

Of the two crises besetting the fossil fuels – the approach of the peak in world production of oil from conventional sources and the need to substantially reduce emissions of carbon dioxide – the important question is which provokes large-scale corrective action first. With the peak in low-cost world conventional oil production likely in the near future, probably no later than sometime in the period 2015-2020, it may be expected that its price and thus those of the other fossil fuels will increase as the peak is approached followed by a significant rise thereafter. Higher prices for oil make it markedly less costly to deal with the reduction of emissions from all three fuels. The reverse situation in which the reductions must be carried out in a lower-priced energy environment of plentiful fuel supply is much more difficult to manage since there is less economic incentive to do so. The Stern Review released in the U.K. in October of 2006 showed that it is less costly to attack climate change now than to wait until the situation becomes more critical later: the extra cost of dealing with the problem as soon as possible was estimated at about a one per cent fall in GDP below what was otherwise expected. This extra cost, though large, is manageable, and was shown to be lower (and safer) than waiting to deal with a potentially much more serious situation later. The extra cost of undertaking significant corrective action to deal with climate change could be even lower if the world production of conventional oil is in fact near peaking. It is thus of great importance to understand the timing of these two inter-related crises.

Human nature being as it is, it is unlikely that expensive and troublesome efforts will be directed to deal with either the peak oil or the climate change problem until there is clear and unmistakeable evidence obvious to just about everyone of immediate trouble. Decisive action will be delayed until 'something sounds the gong.' The present situation may be likened to watching a race to see which problem rings it first. We have seen that the order that this happens is important. We will be lucky if the peak oil problem forces action first, but it is important to be prepared so that the measures adopted in the resulting crisis atmosphere are also those that help address the climate change issue. There will be the dangerous temptation to adopt the cheaper and quicker coal options (including liquefaction processes in countries such as China) without providing for the capture and sequestering of the associated carbon. It is important to prepare plans well in advance to ensure a reasonably optimal path is followed in these quite possibly difficult circumstances.

The uncertainty itself in the price of oil considered independently of its actual level is also important in hindering the adoption of substitutes on either the demand or the supply sides. The present volatility of the price is a major factor in inhibiting action in the current period before the peak in the world production of conventional oil is reached. However, once the peak is past, though the price of oil will be higher, it will also be more stable because it will be related to the costs of the next less expensive substitutes. This stability in price may even offset the economic damage of a markedly higher price to some degree because it will be possible to identify and undertake corrective measures with more confidence.

If emissions from the fossil fuels must be reduced to the sustainable level defined as stabilization of the concentrations of greenhouse gases in the atmosphere, the consumption would have to fall some 60 per cent from present levels unless the techniques for carbon dioixde capture and sequestering (CCS) become widely adopted. Even so, the fossil fuel industry that remained after this reduction would still be very large by any standard. With the adoption of CCS techniques, this limit on production could be relaxed. It is an interesting paradox that the industry would be even larger than otherwise because of the inevitable fall in energy conversion efficiency due to the adoption of the CCS technology. This is inevitable due to the substantial energy requirement to operate the extra process stages needed for this technology: this energy can only be supplied by the consumption of more fossil fuel. Nevertheless, despite this offsetting effect, the total production of the fossil fuels would be reduced under a greenhouse gas stabilization regime. It follows that the remaining resources of the fossil fuels will last longer than otherwise because, in effect, their consumption will be stretched out further in time. In economic terms, with less annual production, these fuels would be lower on the supply curve than they would have been without the imposition of greenhouse gas emission limits. This implies that the resources of the fossil fuels will 'last longer,' so the research and development programs undertaken to ensure their best use will have an extended time horizon to 'pay off.' It is counter-intuitive, but there is a case for more longer term basic research on all the fossil fuels and particularly coal because it has the largest and most widely distributed remaining resource base.

The advent of the capture and sequestering of carbon dioxide emissions from the fossil fuels raises some of the issues reminiscent of radioactive waste management in the nuclear industry. How can it be proved that the sequestered gas can be stored indefinitely? Should the captured carbon dioxide be disposed of permanently or remain recoverable later from storage? Is it possible we will need to retrieve this greenhouse gas at some future time in case of a climate reversal?

Each of the three fossil fuels presents its own challenges in dealing with carbon dioxide emissions. The issues for oil may be summarized as the following: with its many advantages, oil is difficult to remove from the energy system; because of the low technical cost of production of most of the world's conventional oil resources, there will be a strong tendency to use as much as possible of this fuel from these sources; the high economic rent is going to someone, somewhere; with its main application in the transportation field, there are many small independent users where carbon capture is effectively impossible; because the price can fall a long way before production is effectively discouraged, the only real option to reduce emissions from oil is to find measures that delay its use, not substitute for it.

Natural gas presents a different quandary. It has the lowest carbon intensity of the fossil fuels and is the easiest to use at high efficiency: these two advantages are perhaps equal in importance in reducing emissions. When gas substitutes for the other two fossil fuels, overall emissions decline but when it is used to meet new energy needs, the opposite is true. It is more difficult to apply capture and sequestering techniques to conversion processes using this convenient fuel because the effluent or process gas streams are generally lower in carbon dioxide content which increases the cost of operating these stages. In general in the case of natural gas, the carbon must be removed before use by employing the more expensive reforming processes.

There is even a complication in the case of coal, the cheapest of the fossil fuels in many places. Though it has the highest specific carbon content of the three fuels, it is usually easier to apply the carbon dioxide capture technologies to it than to the other fuels in its largest market – the generation of electricity- because of the higher concentrations of this gas in the process streams.

The electrical network is now recognized as one of the great engineering achievements in its own right. It operates with effectively no storage and so must always be positively controlled. Furthermore, the total possible connected load is greater than the maximum connected generating capacity. Operating the network successfully may be compared in some ways to managing the banking system where the amount of money loaned is substantially greater than the deposits that cover the outstanding amounts. The operating problem is to prevent a 'run on the bank.' but the effect of deregulation is to loosen the controls on the system. The expansion of small-scale local distributed generation at the extremities of the grid will improve the resilience of the system most of the time but at the expense of its exposure to more uncertain loads under extreme conditions. With a higher proportion of more distributed generation, fewer minor interruptions to local supply are to be expected but the exposure to major failure will increases because of the relatively smaller fraction of centralized generation at its core. Such general failures may be all the more dangerous for being less common. In one example relevant to Canada, if the natural gas supply system fails for any reason, people will turn on their electric stoves to keep warm and this large and sudden load would no doubt bring down the system. Recovery becomes more difficult if the distributed fraction of the generation cannot be marshalled to act in concert. The electrical system is exposed in the same way as the cell phone system is during emergencies and subject to the same general cause of failure - everyone turns to it at once. Adding additional markets to the grid, such as meeting more of the energy requirements for space heating or powering electric vehicles, poses the question not only how this extra load will be generated but also how it will be conrolled and balanced. The overwhelming consideration is always that the most expensive electricity is that one does not have.

Because the electrolysis process can be disconnected from the grid essentially instantly, the introduction of hydrogen-based fuel cell-equipped vehicles is an example of adding a new load and the method of achieving network balance at the same time. There is the further advantage such vehicles could be equipped with connecting devices in such a way that they could themselves supply household power during major system outages.

The economic efficiency with which energy is used, in the developed countries at least, has slowly but steadily been improving in terms of the fall of the ratio of the total primary energy (PE) consumed to the gross domestic product (GDP). This steady gain in efficiency has been achieved at a price. Over the same period, the quality of the energy supplied has also been rising usually by consuming a higher proportion of electricity. This explains why the strong co-relation between electrical consumption and GDP has been maintained over this period despite the concurrent fall in the PE/GDP ratio. The gain in energy efficiency over the years has occurred even during periods when energy prices have been declining and thus this change has been difficult to build into economic models. Nevertheless, there has long been general recognition that technological advances mitigate costs over long time horizons. In the past, an exogenous term was generally introduced called Autonomous Energy Efficiency Improvement (AEEI) whose value was usually of the order of one percent per year regardless of changes in energy price. Only in recent years has it been found possible to build Endogenous Technological Change - the change in technological characteristics induced by the policies or incentives associated with the study itself (such as the evaluation of climate stabilization constraints) into the models. Advances in current energy studies aim at reconciling the mostly economic 'top-down' approaches so as to meet the mostly technologically oriented ‘bottom-up’ options. These advances are leading to a new understanding of the energy field.

The change in the economic structure of many developed countries - with less emphasis placed on the energy-intensive industries (or even their actual closure) - as part of the current trend towards globalization of the world economy has been a further complication. These changes pose a quandary for Canada in that it is a both a net energy exporter (including most importantly continuing to be a slowly growing net exporter of oil) and a natural host for the energy-intensive industries. This country has a long history in this field supported by the advantages of good water resources and ample space. Along with Australia, it is an anomaly among the developed countries. Yet in most international fora, Canada may be found grouped with the energy-importing countries. Those developed nations that claim lower emissions of greenhouse gases often achieve their results in part by buying energy-intensive goods from Canada or by benefiting from the development of the oil sands of Alberta: the emissions are left behind to be dealt with here. It is important for Canadians to understand our position clearly in a world of emissions constraint. The industrial niche for Canada in the world may still be the efficient operation of the energy intensive industries but this requires an understanding of the emissions involved and the difficulties in coping with them. As a corollary, there may also be a major opportunity for Canadians to specialize in providing the services such as the design, construction, commissioning, and even operation of the emerging technologies (including those developed here) to serve the energy-intensive industries remaining in service in other countries.

The best energy policy is one that is invisible. It is a success when few outside the field think or need think about energy. It is unfortunate that there is no way of attracting the energy system away from oil – it must be pushed – and it is this aspect that brings it to public attention. The goal of energy policy is best stated as one that allows Canadians to live and work as they wish without having to concern themselves about energy. If most people want to live in individual houses and drive cars, then what is required is a system of measures that permit them to continue to do. At the level of the individual family, this desire can be met long into the future with some combination of the plug-in hybrid car and the super-insulated house.

That some new discovery will be made that opens a new future in energy cannot be discounted. Throughout all human history whenever the future appears to be circumscribed, something has come along to open new possibilities. It is interesting to speculate what disruptive advances will occur in the energy system but they will come. This author’s best guess is there will be important advances in the field of small-scale fusion in the near future.

March 2007

19 Lambton Avenue, Ottawa, Ontario, K1M 0Z6
Tel: 613-745-6279
E-Mail: jhwalsh@ca.inter.net
Web: pages.ca.inter.net/~jhwalsh/index.html