The Impending Twin Crises
One Set of Solutions?

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Abstract

The relationship between the need to reduce emissions of carbon dioxide to the atmosphere and the impending peak in the world production of conventional oil is explored in this paper. The presumption is that vigorous action to address either of these issues will not be taken until there is a clear and present danger under crisis conditions. The order of occurrence of the two crises is important: it is a significant finding of this paper that it is easier to deal with both if the oil peak comes before the climate change imperatives rather than in the reverse order. A set of solutions is proposed for both crises which include the development of plug-in hybrid vehicles as a means of transferring a growing proportion of the energy needs for transportation to the electrical system so as to allow time for the deployment of the hydrogen option. Measures by which the electrical network could cope with this new requirement are considered which include the perfection of coal-based processes that can either generate electricity or produce hydrogen depending upon system requirements with the associated carbon dioxide captured and sequestered. The approach taken here is that measures should be sought that free people to live as they wish without their future determined by energy problems.

There are four appendices to this paper of which only the first–*The Problem with Oil*–was published. In this Appendix, the present oil position is examined in more detail. In Appendix 2–*The Intertwined Dilemmas Posed by Natural Gas and Nuclear Power*–posits that the price of natural gas in North America will tend to be set at margin by the price of liquefied natural gas (LNG) delivered by cryogenic tanker from many overseas sources. Given that the peak in the production of natural gas in North America will occur before the peak in world conventional oil production which in turn will precede that of conventional natural gas, this price could be low enough under equilibrium conditions such that electricity generated in combined-cycle processes will be lower in cost than that of nuclear power. Because it is unlikely that equilibrium conditions will be achieved except perhaps during recessions and periods of relative success in domestic exploration activities, for much of the time the cost of generating nuclear power will in fact be lower than generation from gas thus creating conditions of major uncertainty for the industry. In Appendix 3–*The Coal Opportunity*–the options opened by the successful development of processes for the capture and sequestering of carbon dioxide are considered. Appendix 4–*The Importance of the Electrical Network*–deals with the possible evolution of the electrical network as it supplies a growing share of the energy needs of the transportation sector, and how the production of hydrogen could help keep the system in balance.

Introduction

The world faces two distinctly different but related crises over the next decades. The first arises from dangerous changes in the climate resulting from the continuing build-up of heat-trapping greenhouse gases in the atmosphere. The principal greenhouse gas, carbon dioxide, comes from the excessive consumption of the fossil fuels. The second crisis results from the approaching peak in the world's production of oil derived from conventional sources. This critical milestone will be reached sometime between essentially the present (2005) and 2038; the parabolic technique developed by this author places the peak in the period 2015–2020. Because the consumption of the main products of oil are increasingly dedicated to the transportation sector of the economy (approaching 70% of the total use in some countries), the rapid growth in wealth in the developing world outside of Africa – notably Brazil, China, and India – is aggravating the situation greatly as the vehicles in service increases rapidly. To date, there are few viable options for the replacement of oil as a fuel in autonomous transportation applications. Moreover, the capture of carbon dioxide from the very large number of vehicles in the world – though each is a small emitter the total in the aggregate is large – could not be contemplated.

This paper focuses on the interplay between these two crises. The basic assumption here is that people want their present lifestyle to be affected as little as possible by these pressures. Accordingly, the approach chosen is to survey the options available to minimize their impact. This is not to say that some better life style may evolve in the future which requires less energy and results in a reduced environmental footprint. This paper is concerned more with preserving choice in the sense that neither energy nor environmental determinism should make that decision for them. Consequently, it focuses on technological options that in effect buy time for adjustment, time that is now very short on both accounts.

There is a major difference between the two events in that the date of the peak in world conventional oil production may only be known accurately in retrospect because of the uncertainties inherent in this field of study. The situation in the field of climate change is very different. It is assumed here that there will be a critical event that forces immediate remedial action around the world. Otherwise, the corrective measures taken to reduce greenhouse gas emissions will be incremental and marginal, such as meeting the modest requirements of the Kyoto Protocol. Given a major climatic event of sufficient magnitude, the world will have to turn its attention to reducing emissions to their sustainable limit which is defined here as the stabilization of concentrations of the greenhouse gases in the atmosphere. Meeting this limit will require a reduction in emissions of over 50% (perhaps 60%) from present levels, a formidable task indeed. The two crises share another characteristic. Both are concerned with absolute limits. For the first, there is a fixed limit for the concentration of greenhouse gases in the atmosphere and, for the second, after the peak is reached, the production of oil from conventional sources can only decrease. The ease with which the two crises may be addressed depends on their order of occurrence. It is an important finding of this paper that if the peak in oil production comes before a decisive climatic event, the situation is less difficult to deal with than if events come in the fortunately less probable reverse order. This paper explores this and other interrelationships between the two crises and suggests measures that might prove effective in Canada.

The Central Problem with the Fossil Fuels

The great size of the world's fossil fuel industry is the main impediment in dealing with both the peak oil issue and controlling greenhouse gas emissions. In 2004, about 7.3 gigatonnes of carbon in the form of carbon dioxide (26.9 GT as CO_2) were released to the atmosphere and these emissions are still increasing. That year the fossil fuels accounted for 87.7% of the world's primary energy consumption (excluding the biomass and non-commercial forms of energy) though this proportion may be slowly declining. Oil alone provided 36.8 % of the total primary energy consumption that accounted for 42.8 % of the carbon dioxide released to the atmosphere from the fossil fuels. Given that the sustainable limit is defined as the stabilization of carbon dioxide concentrations in the atmosphere, greenhouse gas emissions would have to be reduced to the equivalent of about 2.8 GT carbon per year in total from these fuels. Even if this much reduced level could be achieved, there would still be a considerable degree of warming as compared to the past due to the higher levels at the time of stabilization. The targets set in the Kyoto Protocol can only be considered a start in the reductions required around the world. The main importance of the Protocol is the international institutional structure that has been established to deal with this unique problem.

Another problem arises from the very unequal distribution of emissions between the developed and the developing countries. The world emissions of carbon from the fossil fuels were 1.15 tonnes per capita in 2004; that may be compared with the 4.93 tonnes per capita emitted in Canada. With the rapid economic expansion of such populous countries as Brazil (0.50 tonnes per capita in 2004), China (0.96 tonnes per capita) and India (0.30 tonnes per capita), it is highly likely the need for oil and the other fossil fuels in the developing countries will overwhelm their efforts to increase efficiency at which energy is consumed. Total carbon dioxide emissions from the fossil fuels increased 15.0 % in China in 2004 to reach 74 % of those of the U.S.A.

The size of the industry is such that even if it proves possible to reduce emissions to the sustainable limit as defined here, a very large and important fossil fuel industry will remain. Moreover, if in fact there is a limit placed on the exploitation of these resources, it follows that they will last longer. This effect gives rise to the somewhat counterintuitive conclusion that more long-term research would be justified in the production and consumption of these fuels to ensure their optimal use over their extended life span.

Relevant aspects of each of the individual fossil fuels are considered in turn in the appendices to this paper. The special interrelationship of natural gas and nuclear power is explored as is the importance of the electrical network.

Canada's Uniqueness – Is it a Help or a Hindrance?

Canada is virtually alone among developed countries in the energy field in that it has nearly every possibility on both the supply and the demand side. It is hard to think of an exception but it may lack a high degree of sunlight for some solar collection schemes. In fact, the range of choices is so great, and characteristically so regionally dependent, that coping with this plethora alone has done much to introduce a state of near paralysis in the policy field. Only Australia shares many of these characteristics but, so far at least, that country is deficient in oil. It is very difficult for even a medium-sized country to have the complete range of expertise needed for all the options across the broad energy field especially as the technologies involved become more complicated. For this reason Canada must also decide in which fields to actively participate, particularly in research and development, and which to merely monitor.

The major single difference between Canada and the other developed nations results from the presence of the large resources of bitumen contained in the oil sands of Alberta which rival the conventional oil resources of Saudi Arabia in size. Canada, along with Norway and so far the U.K., is more than self-sufficient in oil but even in those two countries, oil production is either near or past the peak. In contrast, Canadian net oil exports are expected to continue growing though the rate may slow in the coming decades. Apart from the oil sands, additional conventional production is expected from the eastern offshore and later possibly from the far northern frontier regions as well. Thus, in a decade or two, on current trends, Canada will be the only developed country with an oil production surplus.

Canada exports a little over one-half of its natural gas production by pipeline to the U.S. Of the gas consumed domestically, about one-third is dedicated to what might be termed the essential markets in the home and commercial establishment sector that in effect have few other options and must be served as a last resort. The ultimate size of the emerging large requirement for natural gas to supply both heat and hydrogen for the oil sands industry remains a wild card because the current higher prices make other forms of energy, such as coal, some of the recovered bitumen itself (preferably a fraction that is difficult to upgrade), or even nuclear energy, possibilities to displace gas for this need at least to some degree. The most recent geological assessments of the nation's resources of conventional natural gas are still increasing as a result of aggressive exploration activities, but it appears that total marketable production will plateau between seven and eight trillion cubic feet per year sometime before the end of this decade after which the inevitable decline will set in. During the plateau period, total production may well fluctuate around this average by as much as one-quarter of a trillion cubic feet over each year. Conventional gas production is already being augmented by exploitation of the substantial resources of coal bed methane in Alberta and additional supply from this non-conventional source is possible from B.C. More limited such production may also be possible from the Atlantic Provinces in the future. There are large on-shore resources of methane hydrate clathrates convenient to the proposed Mackenzie Valley pipeline that could be exploited in the next decade given success with the current research efforts. Canada may also become the host for several terminals for the receipt of liquefied natural gas (LNG) produced around the world for delivery mostly to U.S. markets, first on the east coast and then on the west. The complicated relationship between this growing supply arriving by cryogenic tanker from these sources (the peak in world conventional gas production is not expected until as late as the 2030s), and the prospects for nuclear power in North America are explored in Appendix 2.

As far as the other geologically-based fuels are concerned, the resources of coal in the western provinces are large. In the past, the prospects for coal were limited not only by the problem of emissions on use but there was also an issue with the effective extent of the resource base. If people were no longer willing to work in dirty and dangerous conditions underground and if they did not want the surface of the land disturbed, the effective reserves were, in fact, not large. The advent of remote robotic mining techniques may significantly change this situation. As far as emissions are concerned, the new clean coal processes promise the reduction of carbon dioxide released to the atmosphere in facilities that can not only generate electricity but produce hydrogen as well. These emerging coal processes may be matched in the electrical network between nuclear power on the one side that is dedicated to meeting the base load, and wind and other renewable forms of energy on the other that provide a variable supply. The coal plant would contribute flexibility to the electrical system by producing hydrogen for fuel cell-equipped vehicles and other applications when the power was not required. In the nuclear fuel field, Canada remains the largest producer and exporter of uranium.

In a narrow sense, Canada should have no problem supplying energy for its own needs for decades. The complication arises from its membership in the North American Free Trade Association (NAFTA) and its adherence to multilateral sharing agreements such as those negotiated within the framework of the International Energy Agency (IEA). In effect, Canada must accept international prices and share physical shortages proportionately with its external customers. These agreements also impinge on measures that may be undertaken to reduce carbon dioxide emissions. The production of energy from the fossil fuels is itself energy intensive and nowhere is this more true than in the case of the oil sands. The consequence is that high emissions of carbon dioxide result within Canada even though the fuel produced may be exported. A very sophisticated greenhouse gas control strategy is required for Canada to be credited fully for the emissions arising from the direct provision of energy from the fossil fuels to its trading partners or indirectly in the form of energy embodied in other energy-intensive goods under the terms of the Kyoto Protocol. To the extent Canada cannot benefit fully from its fossil fuel resources in terms of either lower prices, improved security of supply, or tradable emission credits, this country will be increasingly living in the worst of all worlds. Canada will have greater trouble meeting its greenhouse gas commitments resulting from expanded production but fewer of the possible economic benefits.

Up to now, the contradiction between the expansion of the oil sands industry and the need to control emissions of carbon dioxide could be reconciled by noting that this non-conventional supply of oil was essentially replacing the declining output of the conventional light grades from the Western Canada Sedimentary Basin. The net increase in emissions was not great. Now, however, the oil sands industry has grown to the stage that this position is no longer supportable. The present production (2005) from the oil sands of just over one million barrels per day might increase to some five million or even more barrels per day by 2030. At some point before long, this inherent contradiction between the rapid expansion of this industry and the need to control emissions of greenhouse gases will come to a head.

We have seen that as the only developed country with more than enough energy to meet its own needs over the next decades, Canada is faced with a major dilemma in how to control its emissions of carbon dioxide. It is also faced with a quandary in deciding on what it should specialize. Should it enthusiastically embrace the new technologies that still require much research and developmental effort (the renewables, the conservation technologies, fusion, etc.) or should it bring up the rear and only introduce these likely more expensive options after they have been developed and perfected elsewhere? One compromise strategy is to add the capture and sequestering of carbon dioxide released from the fossil fuels to its roster of expensive developmental efforts in the energy field with the aim of freeing this large and economic source of energy from the limitations arising from restrictions on the emissions of greenhouse gases. At the same time, it could substantially broaden its much cheaper research-level efforts more widely across the energy field.

What Rings the Climate or the Oil Gong?

Though the negotiations leading to the Kyoto Protocol have been widely criticized for their timidity and lack of effectiveness (including continuing opposition from a diminishing but influential minority who consider it attacks a non-existent problem), there has been good progress in establishing the international institutions required to deal with this worldwide issue. There is now a common understanding of the problem and of the nature of the measures needed to address it. A secretariat has been established in Germany with headquarters in Bonn that has developed internationally agreed standards for such things as reporting. Historically, it has been both difficult and time consuming to negotiate the international arrangements required when complex problems must be dealt with. In this case, these include defining the measures required for emissions trading (with its central problem in verification), and the support required for developing countries in the form of clean development mechanisms. Given that world emissions of carbon dioxide from the fossil fuels will have to be reduced sooner or later well below the modest targets set in the first round of negotiations for the Kyoto Protocol, the developing nations, especially the large and rapidly growing emerging powers such as Brazil, China and India, will have to participate fully to set and meet targets for future rounds. Despite the difficulties, there is now an institutional framework in place to attack the problem and this is a major advance. There is, in short, a credible organization in place to ‘ring the gong.’

The issue of peak oil impinges directly on the climate change question. At one level, higher prices for oil leads directly to higher prices for the other fossil fuels, and thus it becomes less costly to contemplate the frequently expensive measures required to achieve savings, whether by increasing the efficiency with which these fuels are consumed or by replacing them with lower-carbon alternatives. The main problem arises from the generally low technical cost of production of conventional oil - there will be strong pressure to consume all the oil of this kind that is discovered. Most mainstream assessments of the world’s remaining resources of this class of oil suggest emissions of carbon dioxide will be excessive particularly during the first half of this century. The problem may be stated this way: there is no replacement technology known at present that will attract the energy system away from the use of oil of its own accord before the peak in production is reached. Before the peak, the introduction of a promising alternative, whether on the supply or demand side, will merely cause the price to decline. This price has a long way to fall before production will be significantly reduced. But even after the peak has passed, there is still a related problem related to the resource base. The post-peak decline curve will likely follow some form of complex logistic curve so that emissions will remain too high for many years. Unfortunately, this question is only now being addressed in oil resource studies.

If the energy system cannot be `attracted’ away from the excessive use of oil, it must be pushed. The imposition of such measures (including rationing in the extreme case as has been recently mooted in the U. K.) are certain to be politically unpopular and so will require an indication of a clear and present danger from unwanted climate change especially as an international consensus will be required before action will be taken. It is interesting to speculate on what might lead to a decisive call to action.

The leading candidate at the present time may well be a dramatic reduction in the Gulf Stream that warms northern Europe. Another might be the significant seasonal loss of water flow as glaciers retreat that could lead to severe summer droughts in some regions. Other critical events might be the release of very large icebergs from either the Arctic or Antarctic regions with a resultant faster rise in the level of the oceans. The acidity of the ocean might approach dangerous levels. A very large river drainage system, such as the Mississippi, might dry to dangerously low levels in the summer. As a matter of practical politics in the international arena, only dramatic effects of this kind are likely to lead to the adoption of the aggressive measures needed to reduce emissions to the sustainable level in the atmosphere.

There is, however, still another possibility that might lead to the imposition of at least an intermediate level of control measures. Actual physical damage is appearing especially in the far northern regions. It is possible that readily identifiable and quantifiable damage could become the basis of legal proceedings. The insurance industry is facing steadily rising losses due to weather events and may well also initiate similar legal steps. The damage may be so great in money terms that even the largest and wealthiest corporations could not risk the threat of such major actions.

The approach of the peak in the world production of conventional oil could also ring the gong but for different reasons. Despite uncertainty as to exactly when the peak will occur, it will no doubt be signalled by an increase in price combined with greater volatility as the peak is approached. In contrast, after the peak, the price may be higher but more stable. Despite the large and negative economic impact of this price, there is a similarity with the climate change problem in that aggressive remedial action is unlikely to be taken before actual physical shortages develop. Though significant increases in the price of oil were experienced in the 2004-5 period, the only actual shortages reported around the world were for diesel fuel in some developing countries where the causes were largely local. Nevertheless, the International Energy Agency, as part of its mandate to prepare for energy emergencies, judged the situation worrisome enough to publish a study in early 2005 of the most effective measures that could be implemented if a sudden physical shortage developed.

It matters which of these two events rings the gong first. In the fortunately more likely case, the peak in conventional oil production will occur before the decisive climatic event. The higher and the more stable prices for oil that results provides a stronger economic driving force to implement the costly corrective measures needed to deal with both climate control and energy issues. Conversely, in the opposite case, if the decisive climatic event precedes the oil peak, the problem will be more difficult to deal with because the corrective measures will be more costly. The importance of knowing the relative timing of the two events justifies much intensified effort to determine when the peak in conventional oil production will occur given that the climatic event, by its very nature, is relatively unpredictable. If the peak in conventional oil production is close at hand, it is an odd consequence that the world may be a safer place.

What to do When the Gong Rings

It is often claimed that the most important single action required to deal with the twin crises is to allow markets to clear. It is true that the inevitable increase in the price of energy will reduce demand and provide incentives for the introduction of the new technologies but there is a major limit to this approach. The market system can only deploy technologies that have already been demonstrated whereas new technologies and their related infrastructure are needed. What is required is to prepare a suite of technological options that are ready for deployment on whose merits there is widespread agreement. The issue of preparation is particularly difficult to resolve in Canada with its many - in fact virtually all – options, and its strong regional differences and interests. There is, however, less uncertainty than in the past. Oil prices were for the most part low during the past two or three decades and there was no clear consensus which of the two problems should be addressed first. Now, whether the problem is seen as the need to cope with higher oil prices on the one hand, or the reduction of carbon dioxide emissions on the other, the required actions are approaching each other to the stage they are becoming more and more the same.

The problem in Canada, as always, is where to begin. In this paper, it is recommended that the immediate focus be on houses and cars because this is where the twin crises bear directly on the individual citizen. The return of a greater measure of certainty in oil prices is especially helpful in convincing people to undertake the necessary actions in these two fields. Much may be learned from past experience. In the last period of upheaval in the energy system in the 1970s and 1980s, governments aggressively advised the public to switch away from oil and actively supported this change with some degree of subsidy. Those who converted their heating systems to natural gas were generally satisfied but those who converted to electricity were not. In the latter case, people were told the cost of electricity would not rise faster than that of the fossil fuels but, in much of Canada, the opposite occurred. They were also advised to install more insulation but it turned out some of the approved materials could emit potentially harmful gases. If very high standards to reduce infiltration were achieved, indoor air quality could deteriorate unless additional ventilation was provided which frequently required the installation of mechanical heat exchangers. Much public scepticism arose with good cause and this difficult experience still inhibits such activities today. Nevertheless, these problems are now much better understood.

The widespread adoption of more energy-efficient houses and cars share a common inhibiting factor. Most of the measures that might be contemplated - if not all - require more investment at the start than their less efficient predecessors. This increase in initial capital cost often confronts buyers, especially those with young families, at a time when the funds to meet this extra investment are short. The higher first cost of additional energy efficiency is, however, compensated by the reduced consumption of fuel over time. The first need is to find an effective way of financing the higher front-end cost of the more efficient technologies. In the main, this is best done by governments.

There have been several attempts at introducing such schemes in the energy field over the years, but most have been half-hearted, complicated, and tentative, and seldom part of an integrated strategy to reduce both energy costs and greenhouse gas emissions. The successful housing programs introduced to help buyers of new homes obtain manageable mortgages in the early post-war years should be re-visited. These should be extended to encourage the building of the efficient energy home with its high standards of insulation and ventilation, including the maximum use of passive solar energy if not the installation of equipment needed for the better active techniques. The post-war housing programs also set a precedent in that a system of sequential inspections was put in place to ensure that at least adequate, and often superior, construction standards were in fact met. These programs could be extended to ensure high performance in the consumption of energy over decades of the life of the structure. In short, long-term high standards for the consumption of energy should be as much a requirement for obtaining and keeping a favourable mortgage as, say, holding sufficient fire insurance.

The housing program proposed here should not be narrowly focused on the structure itself but also include such related matters as the adoption of the new lighting technologies, such as the new light-emitting diodes (LEDs), and more efficient appliances as these become available over the years as they have notably in Japan. These advances in household fittings and equipment also lead to higher front-end costs that must be compensated in some way to encourage more widespread adoption. Economists have long known that the effective discount rate applying to those of low incomes is very high. The poor tend to have to buy too cheaply and thus incur high continuing costs.

Cars present an interesting case in that two quite different forces are at work. The initial choice of vehicle in effect locks the owner in to a certain standard of efficiency for a number of years. The same problem of higher first cost that inhibits the adoption of techniques to lower the consumption of energy in housing also affects the choice of vehicle on purchase. The second issue concerns the factors that influence the extent to which an already purchased vehicle is driven. Though the average cost of driving a unit of distance is quite high due to such fixed burdens as depreciation, insurance, and maintenance, the marginal cost of driving an extra kilometre is much lower in terms of actual out-of-pocket expense, not to mention the great convenience offered by a personal vehicle. It is this aspect of individual car ownership that makes it so difficult for public transport to compete especially in the off hours when traffic is lighter and parking more available. This is an inevitable consequence of the automotive age.

For this reason, the policy recommendation here is the opposite of that generally followed in Canada. Rather than try to increase the marginal cost of driving, it would be more fruitful to do the opposite and reduce it. This is because increasing the marginal cost by such measures as by imposing increased parking fees will not benefit public transport greatly because of the high value people place on their time, their comfort in a cold country, and their convenience. There may be valid arguments for time-of-day congestion charges in some cities such as those introduced recently in London but Canada may by and large not need them. This is not an argument against improving public transport, which should be expanded and made more useful wherever practicable, but one aimed at lowering the cost of marginal driving to encourage the use of plug-in hybrid vehicles so that a reduction in both the consumption of oil and the emissions of greenhouse gases may be achieved at the same time. Canada has an opportunity to achieve this apparently contradictory and counterintuitive objective because of its many sources of electricity. It would benefit greatly from success.

It is possible to convert standard designs of the emerging hybrid vehicles to essentially all-electric operation for short distance runs. This may be done by installing some additional battery capacity (perhaps augmented by capacitors) in such a way that the driver has the option to re-charge from the electrical network during those periods of time the vehicle is not in service. (Already a small California company is offering kits to convert one well-known hybrid production model to plug-in operation.) With depletion of the battery on longer trips, the vehicle switches automatically to the normal hybrid mode by bringing the on-board generator into service without intervention from the driver. The savings in fuel would more than compensate for the nuisance of having to plug the vehicle in overnight or during other long non-operating intervals. With the announced intention of Ontario to install household off-peak electrical metering systems, it may be that this economic incentive will prove decisive. This practice is also encouraged by what is in effect a tax expenditure in the sense that the electricity purchased from the grid does not now bear road taxes, a situation likely to last for at least some years.

Trials of hybrid delivery vehicles with their characteristic stop-and-go driving have also begun in Canada. These tests should also be extended to cover the case of additional battery capacity with plug-in capability where appropriate.

In the railway field, a Vancouver company has developed a hybrid switching locomotive to save fuel and reduce emissions known as the ‘Green Goat’. Though at first glance a minor application of hybrid technology, this converted locomotive may be the forerunner of many railway applications such as road switchers and commuter train operations. Plug-in capability could be added to this class of locomotive because they are often idle for long periods during the day. This apparently small measure could be the start of the widespread electrification of the railway system in Canada.

It is difficult to estimate how much of the gasoline and diesel fuel consumed in the transportation sector could be replaced by electrical energy supplied from the grid, but, for cars at least, short runs are the most common feature of normal everyday driving so that savings are likely to exceed thirty percent of the liquid fuel that would be consumed otherwise.

None of this obviates the need for greater fuel economy in the remaining conventional fleet whose manufacture will no doubt continue well into a long transition period. The wider adoption of modern common-rail diesel engines would be useful. Nor does the advent of the hybrid vehicle detract from the importance of the eventual adoption of vehicles equipped with fuel cells. Hydrogen is likely the ultimate fuel of choice though ethanol and perhaps methanol remain contenders. Ethanol may well be produced from cellulose and other polysaccharides. This easy-to-handle alcohol may be used directly in internal combustion engines or converted on-board to supply hydrogen to power fuel cells. It may well emerge that there is no one single long-term solution to the problem of fuelling autonomous vehicles but these other more conventional options are also inhibited by higher front-end costs.

Conclusion

The twin crises arising from global climate change and the peaking in the world production of conventional oil can be addressed together by adopting a set of self-consistent measures. As the first priority, improved financial arrangements are needed to overcome the barrier to adoption of nearly all the remedial technologies posed by their higher initial cost particularly in the housing and transportation fields. In effect, the mortgage system should be extended to provide funds at a low interest rate to cover the extra `front-end’ costs involved in the housing and domestic appliance fields. The second priority consists of ways of gradually transferring more of the fuelling needs of autonomous vehicles to the electrical grid. The leading near-term option is the conversion of existing designs of hybrid vehicles to a partial `plug-in' operation. This option would be matched with the development of hydrogen-powered fuel cells as a longer-term goal. This second priority requires a parallel set of re-vitalized measures to both strengthen and protect the integrity of the electrical network. The extra electricity required may be provided from a number of sources including wind and other renewable generation, nuclear power, and from coal consumed in facilities equipped for the capture and sequestering of carbon dioxide. The first Canadian 'capture ready' coal generating facility is planned for service in Saskatchewan in 2013.

Hydrogen may be produced by the conventional natural gas reforming process modified to capture over half the carbon dioxide that would otherwise be released to the atmosphere, by the electrolysis of water using off-peak power generated in wind or nuclear sources, directly by the thermal decomposition of some renewable sources or, in the case of coal, as a co-product in the generation of electricity. The latter option is attractive because co-production technologies offer a balancing mechanism to protect the electrical grid in that the hydrogen may be produced off-peak.

The twin crises have indeed one set of solutions, but whatever is decided, time is now the critical question. The high but stable post-peak oil prices will provide the necessary driving force and people are coming to accept the need for aggressive action.

Appendix 1
The Problem with Oil

In discussing the oil problem, it is important to distinguish between oil derived from conventional and non-conventional sources because of the unique characteristics of the former. The low technical cost of production of conventional oil, including its delivery over long distances to major markets by tanker or pipeline, in relationship to its price is the most important of these. As a consequence, there will always be a strong tendency to consume all the conventional oil that is discovered though costs may well be higher in some remote or difficult locations. As a result, its production tends to be limited more by the rate of discovery than any other factor except perhaps in the Middle East where the bulk of the world's remaining reserves exist. It is therefore important to estimate how much conventional oil there is available to the world and how fast it can be discovered and produced from the viewpoint not only of predicting the course of the energy economy but also the related emissions of carbon dioxide. Because such a high (and growing) proportion of the oil consumed is dedicated to meeting the fuel needs of mobile sources in the transportation sector, the only practicable approach to reducing the rate of emissions of carbon dioxide from conventional oil is to slow its consumption by whatever means available. Notwithstanding any success in reducing its rate of production, given the great economic driving force, there will be a strong tendency to use all the oil that is discovered over time given the great economic driving force. Limiting the production of conventional oil by whatever means only extends the oil age in time.

Non-conventional oil, such as that derived from the extensive oil sands of Alberta - where the present production of about one million barrels per day is expected to double or even triple by the end of the next decade and reach five million or more barrels per day in 2030 - may be distinguished in several ways but, in nearly all cases, the output is limited by the rate at which complicated and costly production facilities may be deployed. It is convenient to distinguish between conventional (at the present time the world's oil production is overwhelmingly discovery-limited) and non–conventional sources by classifying any source of oil not in production ten years after discovery as non-conventional. (The oil sands were known to the first European explorers of what is now northern Alberta two centuries ago and to First Nations peoples well before that.) This approach based upon elapsed time since discovery has the advantage of providing a consistent technique for the classification of otherwise conventional oil found in very deep or in unusually hostile environments that have delayed its exploitation. There are also advantages to such a time-defined classification system by linking geological assessments of oil potential to systems analysis studies with time a shared axis.

There are two different strands of thought in thinking about the oil depletion phenomenon at the present time. The first rests on the correct supposition that even in the case of conventional oil, it takes significant time to bring new discoveries into production. It is thus possible to prepare a list of projects known to be underway around the world and estimate their size and timing with a good degree of certainty at least for the next few years. In effect, a near-term supply curve results that is essentially independent of other factors such as price. The worst errors are likely to come from delays to major projects. Such supply curves may then be matched with estimates of demand over a range of scenarios that, in contrast, do depend upon economic conditions. The element that is missing from such an approach to the supply-demand balance is an estimate of the depletion underway in the pre-existing supply system over the same time period. The value of this latter loss is the most uncertain. Authors such as Skrebowski [1] deal with the depletion problem by estimating the net overall loss from the existing facilities. This is done by estimating the balance between the loss of production in existing individual fields and the off-setting gains resulting from such local corrective measures as infill drilling and the implementation of expensive enhanced recovery processes. The net loss is treated as equivalent to a growth in demand. Such loss estimates have generally predicted a gradual tightening of the world supply system an average of between 500,000 barrels per day and one million barrels per day each year over the next decade but this rate of net loss due to depletion is expected to increase with time.

Rubin and his associates [2] at CIBC World Markets have applied economic analytical tools to estimate the increase in price required to clear markets in what is termed 'demand destruction' in a situation with an inflexible supply curve. This form of analysis leads these authors to predict that oil prices on trading markets will exceed $100 per barrel ($US 2005) within a decade. Such calculations must be regarded with some caution since they are based upon general equilibrium theory notwithstanding that the energy system, and particularly its oil component, is generally a long way from equilibrium. Moreover, the new oil supply over the coming decade, though averaging a little over two million barrels per day, varies between one and three million barrels per day each year over this time period. If a good year for the increase in production coincides with a down year in demand due to a recession, the trading price may well fall. For this reason, such calculations do not predict occasional `spikes' or even `valleys' (such as in deep-`V' scenarios) in the oil price arising from a temporary surge up or down due to some current and short-lived circumstance. This approach to the oil issue does not depend explicitly on oil production reaching a peak because, in this class of analysis, production from conventional sources could be assumed to continue to increase indefinitely. Instead, the demand destruction methodology is a technique for dealing with the situation when oil production does not rise as fast as that of demand plus depletion in the expected price ranges. Nevertheless, Skrebowski extends his analysis to flow-type calculations that lead him to place the peak in world conventional oil production in 2008.

The second strand in addressing the oil outlook revolves around the `peak oil' issue. Unlike the previous approach, the physical quantity of conventional oil available to the world is expected to fall at some time due to its decreasing geological availability. Careful evaluation of recent petroleum history indicates that discovery rates are falling behind production rates because it is steadily becoming more difficult to find conventional oil, particularly in large reservoirs. It is thus inevitable that at some point production will peak. The pioneering studies by Hubbert[3] during the middle of the last century relied upon curve-fitting techniques and not geological interpretation in a model that started at zero, passed through a peak at about the mid-point of the resource available and then fell afterwards towards zero. This work did not depend primarily upon geological assessments. In the intervening years, probabilistic techniques for the estimation of the undiscovered resources of conventional oil matured greatly. The application of these techniques not only give a quantitative assessment of the petroleum likely to be discovered but also a framework for understanding the changes in this value that will inevitably occur as exploration proceeds. Most such revisions have been upwards with time but not in all oil and gas provinces, including some cases in Canada. Confidence in the estimate grows as the revisions from further assessments stabilize to a narrowing range of probabilities over time.

There is a central problem in the geological assessment approach: How should these probabilistic results be interpreted? This author [4] has devised a parabolic technique for the projection of geological assessments in terms of an unconstrained production-time function. This method was chosen because the shape of a parabolic curve is free of inflections in the curve on each side of the peak. The parabola also approximates `plateau peaks' well and has certain mathematical advantages in handling the various possibilities. It has the disadvantage of not modelling the decline curve for the far-out years when estimates of carbon dioxide emissions are of more interest than oil production.

The date of the peak predicted by this and other similar modelling equations depends mostly upon the quantity of conventional oil in the assessment. This value is a matter of much dispute at the present time but should become less uncertain with time. The date of the peak ranges from essentially now to 2038 for most assessment results and 2015-2020 using the parabolic technique of this author. Unfortunately, the difficulties are such that it is quite possible the exact date will only be known in retrospect.

There is the related question of the transparency of published data on oil reserves whether that issued by private companies or the production organizations of Middle East countries. Securities commissions and stock exchanges have also sought more reliable and comprehensive data on reserves but unfortunately so far have couched their requirements, in the case of the United States at least, in terms of accounting or legal frames of reference that are not especially helpful.

This issue of the date of peak oil is very important not only because the price may be expected to be much higher than today with its many imponderable effects on the world economy, but also for a second, perhaps less obvious reason. Before the peak, the price may vary greatly depending upon the economic climate of the time with frequent 'spikes' and 'valleys'. In contrast, after the peak has passed, the price will tend to be set by the next least costly major alternative to oil, whether on the supply or demand side. This latter price, though higher, may be expected to be more stable and predictable than the price before the peak. This means that suppliers from the more costly non-conventional oil sources that require heavy investment over long lead times, such as that derived from the oil sands or from the conversion of stranded natural gas resources around the world to liquids useful in the transportation field, will be confronted with much less economic uncertainty. Currently such investors tend to use shadow prices for oil much lower then present trading prices in their planning processes, and this factor alone has limited the rate at which substitutes of one kind or another are being deployed. This tendency may not be entirely a bad thing from the point of view of controlling carbon dioxide emissions, in that it focuses attention upon the most viable technologies. If there has to be such emissions, they should arise in the most economic manner. The higher price makes it much easier to deal with carbon dioxide from a cost point of view, so it is important to know whether the peak will precede the introduction of aggressive measures for the reduction of emissions.

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Appendix 2
The Intertwined Dilemmas Posed by Natural Gas and Nuclear Power

Though the production of natural gas in North America (including Mexico) will reach a peak or at least an extended plateau before the end of this decade, the conventional resources of this gas in other countries around the world are large and peaking is not expected until after 2025 or even later in the 2030s. The best evidence at the present time indicates the peak in North American production of conventional natural gas will occur before that of the world output of oil from conventional sources. Both these peaks will precede that of the world production of conventional natural gas. There is widespread agreement that the three peaks will occur in this order but it is a matter of dispute how much time will elapse between each pair. There are also substantial resources of non-conventional gas available in some tight geological formations, in the form of extractable coalbed methane (CBM), and from the methane hydrates known as clathrates such that the total supply of gas might be augmented more easily from such new sources than in the corresponding case of oil recovered from its non-conventional resources, notwithstanding the growing output from the oil sands of Alberta or the heavy oils of Venezuela.

Though these domestic non-conventional supplies of gas will no doubt become more important as the years go by, steadily increasing quantities of gas will also be shipped to North American markets by tanker in liquefied form as LNG from a number of producers around the world. This gas often has no or only limited local markets with no connecting long distance pipeline facilities but there are other ways it might find its way into the world energy system. So-called `stranded' natural gas with convenient access to deep-water shipping sites may also be converted to liquid fuels useful for transportation purposes. Already a small number of such Gas-to-Liquids (GTL) facilities are in operation around the world usually producing a diesel fuel of ultra-low sulphur content. The low sulphur content is a consequence of the need to protect the catalysts required to promote the synthesis reactions at the heart of these processes. Such diesel fuel may be used for blending purposes in consumer markets to help meet more exacting environmental standards, especially those related to particulate emissions. In addition, there will be a large indirect import of energy derived from natural gas in the form of energy-intensive products such as ammonia for fertilizers, aluminum, reduced iron intermediates as a feed for steelmaking processes, and other products in which a substantial quantity of energy is embodied before shipment. Those planning the export of gas to the North American and other markets are faced with a major decision as to which product they should sell but there is little doubt that LNG will be the principal one.

To the extent that natural gas replaces other fossil fuels, there is a decrease in the emissions of carbon dioxide. This substitution is not simple because the convenience of this gaseous fuel lends itself to more efficient consumption than coal or oil in most cases. Thus for a given energy requirement, there are two effects at work at once leading to the reduction of emissions – the lower carbon content per unit of energy consumed and the higher efficiency with which it is applied. Nevertheless, when natural gas fills new or expanded applications for energy, it causes emissions to increase though more slowly than if the additional need had been met from coal or oil. Already countries such as Canada, France and Russia emit more carbon dioxide in total from natural gas than coal, and more countries will be in this position over time.

The North American market for natural gas is steadily integrating. In several market assessment reports issued over the years, the National Energy Board has found that though this integration is not yet fully achieved or perfect in operation, in general, the continental market is behaving more and more as a single unit. This means the price at any one location will have a known relationship to the price at any other: the difference between the two will depend mainly on the respective transportation costs to the two locations. In such a situation, the price on the main trading market – The New York NYMEX Exchange – serves as an indicator of the price in all markets on this continent. This price is expressed in U.S. dollars per million British Thermal Units (BTU) at the Henry Hub pipeline junction in Louisiana. Separate Canadian markets exist in Alberta and at the Dawn field in southwestern Ontario, but for the reasons given above, the trading prices will be linked fairly directly to the NYMEX price. It follows that if the marginal additional supply of natural gas is in the form of LNG shipped from third countries, the price of the latter will eventually determine the NYMEX price for all the gas trades, whether imported or domestic. (As it happens, the technical cost of the other leading source of non-conventional gas, coalbed methane or CBM, is not far from the technical cost of delivered LNG with the consequence the development and expansion of this domestic industry will reinforce the price determined by LNG despite the very different delivery points involved.) The issue then becomes: What will set the price of LNG?

There are many potential suppliers of LNG around the world and several new receiving ports are planned in addition to the original four in the U.S. These include new projected facilities located in Canada and Mexico to serve the U.S. market. If a reasonably competitive market evolves over time, the trading price based upon the current technological improvements in the LNG supply chain quoted in terms of the NYMEX exchange should be about $US 4.00 +/- 0.25 per million BTU. However, few observers expect a price this low to actually result because, given that North American natural gas production is reaching a plateau or even a peak, it will be very difficult to build LNG shipping and port facilities fast enough to maintain the supply chain linking overseas producers to this continent. (There are even issues related to the availability of sufficient nickel to produce the austenitic steels needed for the cryogenic tanks required.) For this reason, the weight of opinion holds that the price will not fall much below $US 6.00 per million on the NYMEX Exchange except in periods of severe recession or with unexpected domestic successes in exploration.

This issue is an important consideration when nuclear power for the generation of electricity is proposed as a way of reducing carbon dioxide emissions. The main competitor in the U.S. at present is the combined-cycle natural gas turbine equipped to recover energy from the exhaust gases in a steam cycle. This cycle has may advantages: low unit capital cost; the ability to acccomodate incremental expansion in relatively small, controllable stages; relatively low emissions; steadily increasing efficiency of conversion due to advances in gas turbines; time-to-service as little as three years; and a high proportion of off-site factory-built components. The main disadvantage is the current high price for natural gas.

If combined-cycle technology based upon natural gas provides the primary electrical supply at margin for the expansion of the U.S. utility industry, it follows that it sets the equilibrium price for electrical energy. For nuclear power to compete without subsidy, it should meet this price. A dilemma arises because current estimates for a new generation of advanced nuclear plants places the electrical cost as greater than that generated in combined-cycle facilities based upon the equilibrium price of natural gas set by LNG, but at least competitive, if not lower, that the non-equilibrium price actually expected by most observers. This uncertainty, when combined with the usual issues inhibiting nuclear power – radioactive waste management, location problems, perceived lack of public acceptability – invites paralysis in public policymaking. It is interesting that only a relatively small tax on carbon emissions, perhaps of the order of that coming into effect in New Zealand in a year or two ($NZ 11 per tonne of carbon), might prove decisive in choosing an expanded nuclear power option as compared to generation based upon imported LNG consumed in combined-cycle facilities.

The same dilemma also applies to the renewable options for the generation of electricity, including wind and ocean power, and even centralized solar power, arising from this basic uncertainty in the price for natural gas set at margin by imported LNG.

Appendix 3
The Coal Opportunity

The known resources of coal are larger than those of the other fossil fuels. These are also more widely distributed around the world than in the case of oil even if only the fraction amenable to surface mining methods is counted should people, in the rich countries at least, become increasingly reluctant to work underground in dangerous, dirty, and otherwise generally poor conditions. Combined with the growing public opposition to disturbing the land surface for mining in some countries, the effective reserves may be much reduced. The emergence of robotic techniques for underground mining and the development of workable techniques for the underground gasification of coal may alleviate this access problem to some degree.

Coal as a solid fuel is expensive to ship on land but its large scale transport is once again becoming a mainstay of the world's railway industry. In contrast, transport costs by sea over long distances are low by bulk carrier. The prime applications for coal are in the generation of electricity and, to a lesser extent, the production of iron for the steel industry. Coal is the most carbon intensive of the fossil fuels so the problem of carbon dioxide emissions must be addressed to meet greenhouse gas control targets. In 2004, coal accounted for 38.2 % of the world's emissions of this greenhouse gas from the fossil fuels. The consumption of coal gives rise to a number of other emissions that must also be controlled including oxides of sulphur and nitrogen, mercury and sometimes uranium, and particulates.

To permit an increasing consumption of coal, and even its continued use at the present level, a major change in technology is needed that addresses all the emissions at once. The leading candidate is some form of gasification under pressure, usually employing oxygen, followed by a systematic purification of the fuel gas that results. This fuel gas may then be combusted in gas turbines typically operated in combined-cycle mode. The major outstanding problem is how best to separate, capture, and sequester the carbon dioxide produced.

The actual details of the operation of such emerging processes are quite complex but in outline form, the general technique is quite straight-forward. Provided the methane and higher hydrocarbon components of the fuel gas are low as is characteristic of entrained-flow gasifiers, the fuel gas consists of essentially carbon monoxide and carbon dioxide, and hydrogen and water vapour. It is possible to `shift' a gas containing these constituents to a mixture of hydrogen and carbon dioxide by reaction with steam over suitable catalysts. The carbon dioxide may be separated from the hydrogen and then moved by pipeline for permanent disposal in such geological sinks as saline aquifers. The remaining hydrogen may be used to generate electricity in modified gas turbines or in fuel cells, including those on vehicles. Liquid fuels of very low sulphur content may also be produced by synthesis of hydrogen with carbon monoxide, but such an approach leads to unavoidable emissions of carbon dioxide when the liquid is consumed in vehicles. The processes are thus able to both generate electricity and produce a fuel for vehicles with only minor emissions when hydrogen is the product.

The complexity of the processing stages, particularly when the related capture and sequestering steps required for carbon dioxide disposal are included, indicates that the scale of operation would have to be large to minimize costs. This suggests in turn that other industries that require electricity in large quantities and are themselves significant emitters of large quantities of carbon dioxide, such as those producing steel, might locate nearby to contract with the central coal consuming facility rather than undertake the sequestering operation on their own. The central clean coal power facility may thus become the anchor of a fossil fuel-using industrial complex equipped for the capture and sequestering of carbon dioxide.

The question is how such an approach to the generation of electricity, though still technically immature, compares to the nuclear option. Most estimates for the extra cost of generation in facilities equipped for the capture and sequestering of carbon dioxide are in the range of 2.5 to 3 cents per kilowatt hour as compared to a standard modern coal-burning station. There would seem to be not much advantage over advanced nuclear power generation expect where the cost of coal is low as it is in the western provinces. But this comparison might not be valid if large quantities of hydrogen are also needed. To obtain hydrogen from nuclear power stations usually involves an expensive electrolysis stage although there is now renewed interest in high–temperature gas-cooled reactors in some countries, such as China and South Africa. In this class of reactor, helium may be heated to a sufficiently high temperature to supply the energy needed for the application of thermochemical processes for the splitting of water. When these techniques are used in place of electrolysis, the inevitable losses inherent in the Carnot cycle for the generation of electricity are avoided. Despite this possibility in the nuclear field, the emerging clean coal complexes may prove more attractive for the combined generation of electricity and the production of hydrogen. Such processes might also find application in the oil sands industry of Alberta.

The major advantage of the clean coal complex may be its flexibility in meeting the fluctuating needs of the electrical network. The coal complex may be designed to have the ability to either generate electricity or produce hydrogen at different times of the day depending upon the load on the system. Such an installation would fill an intermediate position for the support of the electrical grid in that it could help match generation from the purely based-load conventional nuclear reactors with that derived from such highly variable renewable sources of growing importance as wind turbines, solar installations and, in the future, tidal, wave, or water flow installations.

While the need for the capture and sequestering of carbon dioxide from coal is greater than from the other fossil fuels, it is ironic that the first large-scale operation of this kind has been undertaken in the natural gas industry. At the Sleipner West Platform in the Norwegian sector of the North Sea, some one million tonnes per year of carbon dioxide separated from raw natural gas that previously would have been released to the atmosphere is now sequestered in an aquifer under the ocean. In Canada, carbon dioxide captured from an American facility in Beulah, North Dakota, producing synthetic natural gas (SNG) from low-cost lignitic coal is piped to the mature Weyburn field in Saskatchewan for the enhanced recovery of oil. A substantial fraction of the carbon dioxide remains sequestered underground permanently

Another possibility for the sequestering of carbon dioxide also arises in the case of the reforming of natural gas that may complicate the prospects for hydrogen production from coal. About two-thirds of the carbon supplied in the natural gas feed is routinely separated in present conventional operations for the production of hydrogen. This gas may easily be captured and thus may be readily sequestered where suitable aquifers are available. It is thus possible to produce hydrogen from natural gas by a conventional process already in operation with much reduced carbon dioxide emissions. This possibility is under active study in Alberta. Such an option may well inhibit the production of hydrogen in clean coal complexes in the west where coal is cheapest.

Appendix 4
The Importance of the Electrical Network

Though less energy is consumed now in total per unit of wealth generation than during the energy crises of a generation or so ago, this is not a simple relationship as there are complicating factors that must be considered. One of the reasons for the improvement of this macro measure of efficiency is that energy-intensive industries have been moving to those countries generously endowed with either fossil fuels or hydroelectric power sites. The consequence has been an increase in energy embodied in the materials traded in world markets. Another reason is the higher quality of the energy now consumed in the developed countries. In general, this has meant an increase in the relative importance of electricity: the transmission network is increasingly being recognized as one of the great inventions of mankind in its own right. Most of the time it works well and is almost invisible to the public; when it breaks down, there are few people that are not affected one way or another. The issue is how this remarkable web will develop in the future.

It is useful to consider the essential characteristics of the electrical web. In practice, there is very little electrical storage in relation to the size of load. Though there are pumped storage schemes, the increasing use of flow-type batteries, and the adoption of load levelling measures of one kind or another, the great preponderance of electrical energy is consumed the instant it is generated. Moreover, the electrical network is not self-regulating: it must be positively managed. It is a natural command-and-control system. (In a fully deregulated electrical market, there is still the need, perhaps an even greater one than otherwise, for an Independent System Operator to carry out this function.) As the recent experience with wide-area blackouts confirms, the most expensive electricity is that one does not have. It is also true that the electrical network operates with more connected potential load than the installed generation capacity can supply. In the last energy crises during the 1970s and 80s, it was apparent that there was a fundamental difference in public attitudes between the U.S.A. and Canada: in the U.S.A., people were concerned chiefly about how to keep their cars running while Canadians (at least in Winter) were more worried about how to keep warm. Had there been a physical shortage of heating oil or natural gas, Canadians would have turned on their electrical heaters or their cooking stoves. There is doubt that the electrical system could have handled such a major sudden increase in load even by implementing such extreme measures as rotating load shedding. It is ironic in the present situation that the electrical network is still needed for the operation of furnaces fuelled with oil or natural gas including heat exchangers and heat pumps that rely upon air or ground water energy sources. This is also true in some cases where local wood is the fuel.

There are two trends at present that raise major issues for the electrical network. The increase in renewable sources of energy, especially the growing number of wind turbines, gives rise to variable supplies that must be managed. Currently, the general opinion is that the network could accommodate up to as much as 25% of its supply coming from such relatively unpredictable sources. More electricity will no doubt be generated in solar cells as well, but this energy is only available in daylight hours, its strength depends upon the extent of the cloud cover, and generation is least in winter. One of the possibilities open to Canada for dealing with this intermittent supply problem is the operation of certain hydroelectric facilities on a peak demand basis as is now practiced at the Carillon Dam in the Ottawa area.

The second trend is the possibility of increases in distributed generation such as that resulting from the installation of solar cells on individual houses. To operate economically, such solar power options require a functioning network because surplus energy is fed to the network when in surplus and withdrawn at night or during periods of peak requirement. The network is expected to cope with the large loads that occur on the coldest and darkest days.

The installation of modern metering systems is the first line of defence of the network to deal with these emerging trends. When power is purchased, the price is set at various rates that apply at different times of the day: householders and other users are expected to adjust their consuming behaviour accordingly. (It is an interesting question as to whether variable rates will apply to power fed to the network from myriad independent solar collectors). A major effort will be made to install such meters in Ontario in the coming years. The current rapid advances in the information technology field is an inhibiting factor for an odd reason: the techniques for measurement and control may advance faster than they can be implemented so much so that the future better may paralyse the installation of the present good.

There are three emerging possibilities that may materially change the characteristics of the network and increase its relative importance. At margin, more Canadian homes are heated with natural gas than any other fuel. Notwithstanding this trend, there is now extensive experience with high standards of insulation and appropriate measures for the passive recovery of solar energy: a relatively small additional investment can reduce fuel consumption substantially though heat recovery exchangers are often needed to allow the circulation of adequate air for ventilation and for moisture control. Energy consumption can be reduced so much that electrical heating is attractive because of its lower capital cost and ease of control though the price of electricity is higher than the other fuels. This is because the homeowner becomes indifferent to its unit cost when so little must be consumed. The disadvantages of super-insulated houses is that the first cost is higher (typically +$5 to $10,000), and that air conditioning is more difficult if no ducts are installed as may be the case when the least expensive resistance heating systems are used. From a societal view, there may be less need for the expensive gas distribution system particularly in rural areas. Nevertheless, the widespread adoption of electrical heating systems of one kind or another, no matter how energy efficient the new house, adds to the load on the network, a load that increases in winter.

The second emerging option applies mainly to larger structures such as apartment houses and commercial establishments, hospitals and the like. Natural gas may be used to operate small generators – reciprocating engines, microturbines and ultimately fuel cells–with the sensible heat recovered from power generation used for space heating and the supply of hot water. Such co-generation (sometimes termed combined heat and power) modes lead to a very high overall fuel conversion efficiency, perhaps in the range of 70-80%. These installations require the network either to supply marginal quantities of electrical energy or to carry the surplus away depending upon load conditions. It is not clear how the integrity of the network would be affected by the widespread adoption of CHP installations of this kind. At one level, the network is stressed by another set of uncertainties but it is also true these options can be large enough to offer stabilization over wide areas in the event of a widespread breakdown. This approach is especially attractive for institutions such as hospitals who must install backup generation equipment in any case.

It is the third emerging option that has the greatest promise but may lead to the most difficulty. The growing public acceptance of the hybrid vehicle offers a major opportunity especially for Canada with its relatively strong electrical network. It seems clear that in the absence of major advances in the battery field, the all-electric vehicle will find only niche markets. Hybrid vehicles, however, offer the opportunity for plug-in recharging during off hours at home or at other times when the vehicle is not required for service. At the same time, its quality of service is no way restricted by the possibility of partial recharging from the network. It may well be that a substantial reduction in the consumption of gasoline or diesel oil may be achieved in this way. From a societal viewpoint, the early stages of this option is driven in part by a tax expenditure because no road tax appears on the electrical bill and need not for some time until there are sufficient numbers of this type of vehicle on the road to materially impinge on road revenues. (The plug-in option also provides a source of electricity to the householder in emergencies, and this feature would have been very helpful during the ice storm of a few years ago when so many natural gas-based furnaces could not operate.) There is a need for greater battery capacity (including possibly capacitors) than now supplied with the present designs of hybrid vehicles but there would seem to be no great problem in meeting this requirement. Already a California company is offering a plug-in conversion kit for one of the well-known hybrid vehicle models.

Later, vehicles powered with fuel cells operating on hydrogen, and possibly the more convenient liquids ethanol or methanol, pose even more questions for the future of the network. Given that the capital cost of the fuel cell is already sunk in the purchased price of the vehicle and that the efficiency of the conversion to electricity is not a strong function of scale, the issue arises as to whether power should not be supplied to the grid from this class of mobile source as a routine matter. No doubt there will be niche applications such as the supply of power to remote cottages that require electricity only during the limited time when people are present. This is in contrast to the more likely reverse case when hydrogen is produced by electrolysis using the network connection at local supply centers or even in the home for fuel cell-equipped vehicles.

Apparently minor advances may have unexpected consequences in the linking of the electrical and transportation sectors. A Canadian company has perfected a hybrid diesel electric switching locomotive in the Vancouver area. In this case, conventional heavy batteries are acceptable because sufficient weight is needed for good rail adherence. A smaller diesel may then be used than otherwise and, because such switchers spend much of their time idling, there are both fuel consumption and environmental advantages. This technique for powering locomotives may be readily converted to a `plug-in' assist from the grid during idle periods. Hybrid-powered engines are now being considered for road switching and commuter train duty that could in time be equipped with `plug-in' capability for re-charging during waiting periods. This Canadian development may well offer a backdoor route to the eventual electrification of the railway industry.

The possible integration of the electrical network with the transportation industry is the great imponderable for the future. Given the successful development of flexible clean coal complexes that can both generate electricity and produce hydrogen with negligible emissions, the possibility exists of an economic supply of energy for fuel cells serving both stationary and mobile applications. The electricity generated directly could partly meet the needs of plug-in hybrid vehicles. The electrical network would become the intermediary balancing the flows of electricity and hydrogen to fill the needs now filled almost exclusively by oil.

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