The World Energy Situation after the Peak in Conventional Oil Production has Passed

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Abstract

Most authorities expect the world output of conventional oil to peak in the next decades but there is no consensus as to when. Estimates of the timing of the peak range from as soon as 2007 to as late as 2037 in the case of the Energy Information Administration of the U.S. Department of Energy. By applying a parabolic projection technique to data from the Mean Case of the Year 2000 Assessment of world resources published by the U.S. Geological Survey, this author found that this watershed in the energy system will occur in the period 2017-20. Before the peak is reached, the oil and thus the energy system as a whole will continue substantially out of internal equilibrium because of the present unstable inverse pattern for the supply of oil. Expensive options such as the oil sands of Alberta are being expanded while large reservoirs with low technical costs of production are idling mainly in the Middle East. Only during times of economic downturn is there an approach to equilibrium conditions.

This paper deals with the situation anticipated after the peak has passed. There will no longer be any reason for the inverse pattern of oil supply to persist because all major discovered sources will be in production by that time. Though prices will be higher, the energy field as a whole will behave more rationally on this account. Instead, a very different problem is likely to arise which may once again result in internal disequilibrium. It may not be possible to supply liquid fuel from non-conventional sources fast enough to avoid the simultaneous deployment of more expensive sources out of minimum-cost sequence. The paper explores some of the factors involved in the rapid deployment of energy options and the relevant limiting factors in the context of supplying energy to a growing vehicle fleet. The object of a successful energy policy should be to maintain the system as close to internal equilibrium as possible.

Introduction

Among geological and other non-economic authorities there is wide acceptance of the view that the world production of crude oil from conventional sources will peak during the first half of this century. The main disagreement is when this will occur. Some authors such as Campbell[1], Deffeyes[2] and Duncan[3] believe the peak is imminent and probably will be reached during this decade. Organizations such as the World Resources Institute believe the peak will likely occur about 2020 and attach considerable importance to this future event.[4] Reynolds ascribes the probability of an early peak in part to the risk averse nature of national oil companies.[5] Experts at the Energy Information Administration of the U.S. Department of Energy have suggested that the peak will occur about 2037.[6] Nevertheless, the recent comprehensive study of the World Energy Council prepared in cooperation with the Institute of Applied Systems Analysis (IIASA) in Laxonburg, Austria, merely notes that the resources of fossil fuels appear adequate for the remainder of this century.[7] Economic authorities, on the other hand, tend to believe either there will be no peak or that it will prove of no significance.[8]

Based upon the predictions of a new parabolic method applied to the most recent world oil assessment prepared by the U.S. Geological Survey[9], this author[10] expects the peak will occur in the 2017-2020 period for the USGS Mean Case with the range extending from as soon as 2012 to as late as 2026 for the high and low probability cases. This forward-looking technique is not related to previous parabolic methods such as that devised by Hubbert[11] whose projections depend upon the pattern of past oil production. Nevertheless, the techniques of Hubbert, Duncan, Reynolds and this author share the conclusion that the predicted date of the peak is not very sensitive to the quantity of oil that may be found. The unexpected discovery of additional large quantities of conventional oil will not delay the date of peak production greatly. For example, the assumption of a large quantity for the world's endowment of conventional oil (greater than 3000 gigabarrels as does the U.S. Energy Information Administration) still results in a peak occurring before 2050.

This finding arises essentially as a consequence of the properties of large numbers and leads to confidence that the peak will occur sometime during the next decades. This paper has been prepared to illuminate the implications of the passing of the peak on the world energy system.

The Situation Before the Peak

The Attributes of Oil and their Consequences

In the previous companion paper[12], the three main attributes of oil were found to set it apart from the other fossil fuels. First, oil and its main products are energy-dense liquids that can meet essentially all energy needs one way or another. It is much more difficult to cover the whole range of applications with the other fossil fuels. Second, oil is cheap to transport long distances either by tanker on the sea or by pipeline overland. Energy in the form of natural gas costs four to five times that in oil to move by pipeline and must be converted to liquefied form (LNG), a costly process, for shipment by tanker. Coal is expensive to move on land by railway though it is cheap to ship by bulk carrier on the oceans. Third, oil is produced in an unstable inverted supply pattern. Very low cost reservoirs mainly in the Middle East are idling whereas expensive oil sand facilities in Alberta are operating at capacity or even being expanded. This unusual behavior could revert to a more normal supply pattern at any time. After such a correction the lowest cost sources would tend to be produced first. Despite the inherent instability of this unusual and possibly unique supply arrangement (except perhaps for diamonds and some pharmaceuticals), and despite wars and economic downturns over the years, this inverse production behavior has persisted for the last two decades or so.

There are two main consequences arising from these attributes. First, the owners of oil may penetrate the energy market to any extent, at any time, and, given an open trading system, at any place they wish by simply reducing the price. Second, any attempt to introduce significant new energy supply initiatives, or even major measures to reduce demand before the peak in production is reached, will only result in a decrease in the price of oil. This price has a long way to fall. Based upon the experience of the early 1990s, the practical floor price may be as low as $US 8-10 per barrel because, at this level, cash flows tend to go negative on many offshore platforms and other complex production facilities. Periods of high prices lead to permanent non-equilibrium effects. The previous sharp fall in prices during the 1980s led to asymmetric effects in the measures implemented to deal with the oil crisis of the time. Thick insulation installed to reduce heating costs in homes and other structures in anticipation of rising energy costs are not removed if energy costs in fact fall later.

The Constancy of World Per Capita Oil Consumption

It is widely believed that it is very difficult to predict events in the energy field and the oil sector in particular. Yet for the past eighteen years the world consumption of oil has been effectively constant at 4.43 barrels per capita with a standard deviation of 0.07 barrels per capita per year.[13] To predict the consumption of oil with reasonable accuracy during this period, all one had to know was the world population. This effect may be explained by the division of world consumption between two quite different groups: a smaller, richer group of about one billion people who consume a large quantity of oil per capita although with steadily rising energy efficiency in contrast with a larger and poorer group of a little over five billion who have been increasing their still small consumption per capita at a much higher rate. Adding extra cars in a region of few vehicles results in the growing consumption of oil even if the vehicles concerned have good fuel economy. An efficient light bulb will save energy if it replaces an inefficient one but will lead to greater energy consumption if none were used before. The balance between these opposing effects in the two groups is thought to lead to this remarkably stable empirical finding of constant world per capita consumption of oil. Given this situation, there may be large changes in prices from time-to-time but the overall per capita consumption will not change greatly.

This question is important because the world per capita consumption of conventional oil peaked at 5.45 barrels in 1973 and it is unlikely that this value will be surpassed in the future. In this more restrictive sense, we are already living in the post-peak period of oil. Over the wide range of estimates of future conventional oil discoveries expected by the U.S. Geological Survey, per capita production of conventional oil is predicted to fall from now on notwithstanding the constancy of its per capita consumption during the past nearly two decades. (See Figure 6 of Reference 10.) The fall in per capita production is thus expected to begin prior to the peak in total world production. Nevertheless, the full significance of falling per capita availability of conventional oil remains elusive. No obvious major problem has been experienced from the decline from the earlier peak in per capita consumption in 1973.

The Non-Conventional Production of Oil

As the peak is passed, all the conventional oil available at that time should find a ready market with the exception of some special cases in the Middle East. During this period, demand for the more costly non-conventional oil supplies will rise. For the non-conventional options of enhanced oil recovery from depleted conventional reservoirs, oil sands, heavy oils, and perhaps even oil shale, the so-called 'backstop' costs are in the range of $US2001 20-30/barrel for those sources requiring investment in new facilities. The conversion of natural gas to liquid gasoline substitutes will be in the same range of supply prices in regions with surplus gas reserves beyond the connecting pipeline systems. The negative cash flow point for operating the range of non-conventional facilities of this kind might be between $US 10-15/barrel. The conversion of coal to liquids is important in this context because the resources of this solid fuel are large enough on a world basis to provide a significant supply of non-conventional oil production for a long time. For this reason, coal liquefaction technology should set a final cap on the price of oil, at least in principle. The supply price from coal-based processes is less certain than the other options but may be in the $US 35-50/barrel range at present. It is noteworthy that the U.S. Department of Energy has set an objective of $US1990S 25/barrel for their research efforts to perfect both direct and indirect coal liquefaction processes. The general cost level of all these non-conventional approaches to augment the supply of liquid fuels is a quantum jump higher than the technical cost of producing oil from most conventional reservoirs.

Any decline in demand resulting from a recession would normally be met by reducing the output of the more expensive non-conventional production. The remaining conventional oil facilities with their low technical costs would remain in full production. In this situation, the price of oil should be held to the cost level of the most efficient non-conventional production still operating given at least an approximation to equilibrium conditions.

Oil and the Carbon Dioxide Problem

Considerations of the effects of reaching the peak must also deal with the need to control carbon dioxide emissions. In 2000, when the three fossil fuels provided 89.7% of the world's primary energy consumption,[14] oil was the source of 45.8% of the carbon dioxide emissions from these fuels.[15] Before the peak, the emissions situation is paradoxical due to the present inverse supply pattern which will likely persist until the peak is reached. This unusual behavior results in the consumption of more coal and natural gas than would otherwise be the case. However, because coal is a more carbon-intensive source of energy than oil and natural gas is the reverse, this effect roughly cancels. After the peak, because the price of oil and thus the other fossil fuels will be at the same time both higher and more rational, and given that most conventional sources will be working at full capacity, there is no reason for the inverse supply behavior to persist. This change should help in the design of measures to control emissions of this gas—a higher and more predictable price for oil should assist in the control of emissions by making more environmentally acceptable substitutions both less costly and risky to implement.

There is a second paradoxical aspect of the carbon dioxide issue. Over time, the remaining available conventional oil will be increasingly concentrated in the Middle East. Because of this low-cost supply, the average technical cost to produce the remaining conventional oil in the world may actually fall for some period of time. If carbon dioxide emissions are to be limited, this is the fossil fuel that should be produced first on normal least-cost grounds. In return for assured markets in a period when the control of carbon dioxide emissions may limit output, it is possible an agreement could be negotiated whereby the large increase in cost resulting from the adoption of expensive techniques for the capture and sequestering of carbon dioxide by consumers might be offset to some degree by the consumption of oil of low technical cost of production from certain producers.

It is thus important to know when the peak in production of the conventional grades of oil will occur on environmental grounds alone. Given the assumption that all the conventional oil discovered will ultimately be produced on least cost grounds, the projection of this output provides a base scenario of minimum carbon dioxide emissions over time.

The Conventional Natural Gas Situation in North America

There is a possibly troublesome issue related to natural gas specific to North America in the pre-peak period. For the world as a whole, the peak in conventional natural gas production will occur two to three decades or so after the peak in conventional oil production. The opposite is true on this continent—the peak in conventional natural gas output will occur here before that of conventional world oil production. The National Energy Board expects Canadian conventional gas production will peak sometime in the period 2008-13 and U.S. conventional production is already past its maximum. Within a decade, significant additional gas supplies will be needed from non-conventional sources such as the extraction of methane from unmineable or unwanted coal seams and from the expanded delivery of natural gas in liquefied form (LNG) carried in specialized tankers from other gas-rich areas of the world including the Middle East. The delivered cost of these two non-conventional sources is approximately the same although the location of the production of the one and the delivery sites of the other may be very different and in effect complementary to each other.

On present trends, nearly 90% of the new electrical supply in the U.S. over the next decade or two will be generated from natural gas consumed in combined-cycle gas turbine facilities characterized by high efficiencies of conversion. The question then arises whether the price of gas will increase sufficiently in North America to encourage the substitution of large quantities of liquid turbine fuel derived from oil in the near term. This issue may prove important because there is time for at least two periods of low prices before the peak in world conventional oil production is reached. Should liquid turbine fuels gain a major foothold in electrical generation in North America before the peak, the stage is set for a major dislocation later (at least in the U.S.) when the turbines would likely be fuelled with natural gas again. This sequence of events would also be a source of considerable stress for Canada given that this country is a growing supplier of both gas and electricity to the U.S. market.

The Choice of a Function to Model the Peak

Due to the very large quantities of conventional oil produced in the world as a whole and the smoothing effect of summing the output of many reservoirs at different phases of their productive lives, a gradual approach to and decline from the peak in conventional oil production is to be expected. For this reason, the parabola was chosen to provide a good representation of reality in the earlier papers. This function traces a smoothly changing top without sharp changes in slope: there are no points of inflection on each side of the peak to restrict its shape as there are with error or most other mathematical functions. The actual date of the peak may be uncertain over a few years. The exact year may only be known in retrospect as when Hubbert's prediction for the date of the peak in conventional U.S. production was confirmed.

The Post-Peak Period

The central question addressed in this paper may be summarized as: What happens after the peak has passed? At that time, we may assume that the need for oil is greater than the supply available from conventional sources even with the demand constrained by the generally higher prices expected then. As far as the discovery of the remaining conventional resource potential is concerned, all reservoirs should come into production as they are discovered without delay with the possible exception of some fields in Saudi Arabia and perhaps in one or two other countries in the Middle East. There is no longer any reason for inverse pricing and the energy system will become more rational on this account. The price of oil should be set by the next least costly alternative capable of making a significant contribution to the market. However, a problem with price `overshoot' may be expected due to restrictions on the rate of maximum deployment possible except perhaps during economic slowdowns. The energy system will thus still be out of internal equilibrium much of the time after the peak is passed but for this very different reason.

With higher prices, oil products will be displaced more rapidly from stationary markets than mobile ones because more choices are available for the fixed applications.This means a higher proportion of the remaining conventional oil and the non-conventional sources produced in its place will be devoted to mobile sources. Those non-conventional sources that produce a high fraction of their output of a suitable quality for mobile applications will be favoured.

The Supply of Liquid Fuel from Non-Conventional Sources

Notwithstanding the growing concentration of conventional oil for the supply of mobile applications, the key problem will be the need for liquid fuel from non-conventional sources. The gap opening between the slowly growing demand and the slowly falling supply of conventional oil will result in a rising demand for liquid fuels from non–conventional sources. We have seen that this requirement might be obtained by applying advanced and more costly enhanced recovery techniques to depleted conventional reservoirs, from new supplies derived from the oil sands of Alberta and the heavy oil belt of Venezuela, from oil shales which occur in a number of countries, and by converting natural gas ‘stranded’ beyond the normal pipeline systems to liquids. Some coal may be converted to liquids as is already the case in South Africa. These sources have a considerably higher technical cost.

The quantity of liquid fuel required from these non-conventional sources will be estimated here in two different ways. First, the world consumption of oil per capita will be assumed to remain approximately constant at its present value for another decade or two. This approach reflects the greater growth in population among the poorer countries and their slow but steady entrance into the automotive age. The difference between the oil consumed on the basis of a moderate population growth scenario (peak of eight billion in world population assumed in 2050) and the value for the falling conventional production predicted for the Mean Case in the U.S. Geological Survey assessment (illustrated in Figure 1 of Reference 10) may then be calculated. The non-conventional supply requirement estimated in this way increases to about 8.2 million barrels per day as soon as 2020 for a peak occurring in 2017.

The second approach involves calculating the per capita consumption calculated from the parabolic production prediction and the same world population scenario as in Reference 10. Assuming this value of 4.08 barrels per capita in the peak year of 2017 stays approximately constant to 2020, the difference between the demand for oil and the conventional production predicted for the latter year is 1.75 million barrels per day. This difference would have to come from new non-conventional sources installed over the three years past the peak if savings and other substitutes did not reduce the per capita consumption substantially in the meantime.

The major issue is whether the generally more capital-intensive facilities required for additional non-conventional supply can be deployed as rapidly as required to fill the increasing gap in the supply for liquid fuels in the post-peak period. A generally stable and higher price for oil will be a major advantage in encouraging deployment after the peak is passed. Nevertheless, it is quite probable non-conventional output will prove to be limited by the maximum possible rate of deployment of the various technologies employed, although some new recovery technologies such as Steam-Assisted Gravity Drainage as applied to the deeper resources of oil sands in Alberta may prove quite flexible and scalable. Nevertheless, based upon Canadian experience with the difficulties in the development of the oil sands, there is no easy answer to this question.

Should the total demand for liquid fuels prove less than the contracting conventional oil supply during some period after the peak is passed, as might be the case in a severe recession, the price would be expected to decline down a rational supply curve. This is because all the low-cost conventional oil brought into production at the time of the peak would remain in service and output from the more costly non-conventional sources would be curtailed to meet the reduced market requirement. This sequence of events is in marked contrast with the present situation.

The Behavior of the Energy System after the Peak

We have seen that the main problem after the peak in conventional oil production is approached and surpassed will be the difficulty in supplying sufficient liquid fuels (or their substitutes) for mobile applications in the transportation sector. There is doubt that enough oil from the more costly non-conventional installations can be supplied fast enough to prevent the system overshooting the ‘capping’ price set by the next least cost supply sequence. The risk is that the energy system will tend to deploy more expensive options simultaneously and out of sequence. The energy system could thus fall once more substantially out of internal equilibrium. Only if demand were to fall during economic recessions would the non-conventional options be introduced in a sequential, least costly manner. The extent of this problem thus depends upon the characteristics of these other supply options and their maximum possible rate of deployment. The same issue also affects possible measures to reduce demand—market imperfections and barriers abound in economic systems out of internal equilibrium.

The deployment problem will be considered in two parts here—first, the issues involved in the identification and selection of the next least costly alternative, and then second, the factors that limit its rapid expansion. Unfortunately, the identification of the next least costly alternative is often complicated by the question of the long-lived technologies. In the energy system, this issue may come down to how to choose between technologies of lower first cost but higher operating costs and those with higher first costs but lower operating costs and which remain in service a long time. It is not clear that the tools available at present to make this choice are adequate.

The deployment issue may concern a specific technology such as nuclear facilities or a complex delivery system as a whole such as might arise in the provision of a hydrogen supply for fuel cell-powered vehicles. Options such as the more widespread use of natural gas-based vehicles occupy a middle ground. As far as the maximum feasible rate of deployment of a single identified technological system is concerned, the issue is further complicated by the fact that in important cases, notably energy from nuclear sources, individual facilities tend to take a long time to deploy given their higher unit capital costs. In the rapid expansion of a technology with this characteristic, several reactors would have to be in the construction and commissioning phases before there is any increase in electrical generation.

In the case of the rapid deployment of a new delivery system, such as may be required for hydrogen, more often than not the individual new installations can be brought into service incrementally which is a major advantage. Elements of a hydrogen delivery system, for example, can be built unit by unit.

The Characteristics of the Long-Lived Technologies

The hydraulic generation of electricity is the prime example of a long-lived technology in the energy sector. Canada has many years of experience in this field and in 2000 generated more electricity in this way than any other country. Facilities over 80 years old are still running and show no signs of becoming obsolete—only maintenance is required though it is true there may be some reservoirs that fill with silt over time unless adequate flushing procedures are either possible or followed. It is thus useful to examine how this form of generation might have been selected for deployment in the past before its construction. The same issues arise today directly in the nuclear power field and more indirectly in the deployment of hydrogen supply systems. In the nuclear power field, stations designed for service lives of about forty years are now being licensed for a further twenty in the U.S. provided certain mandated modifications are carried out. Even the service life of fossil fuel stations of classical design is being extended significantly.

There are three distinct steps involved in the choice of the hydroelectric option for electrical generation. There is (1) the selection of hydropower over other possible competing electrical supplies (historically over some form of fossil fuel-based generation, then usually coal-based), after which (2) making the selection among different possible undeveloped sites, and then (3), having chosen the site, deciding the related remaining question as to how much of its total energy potential should be developed. This last issue is important because the decision is usually irreversible once the dam is constructed.

It is easy to say that the lowest cost source should be developed first. But which technology is the cheaper in the long run? How much of the potential of a hydro site should be developed when redevelopment is effectively precluded in the future? It is apparent that in the classical period of hydroelectric development in Canada, these issues were relatively easy to deal with. If the hydro sites were available they were built although not necessarily very well as were the Chaudiere Falls site in Ottawa and the Lasalle Generating Station which was only partly built across the St.Lawrence on Montreal Island. When the easy sites were exploited, a coal-fired station was built. Environmental concerns rarely entered the equation. Nevertheless, though hydro and fossil fuel generation have very different environmental externalities, there is no problem in principle with making this calculation although in practice these latter costs can only be estimated with difficulty.

The problem considered here is quite different in that it involves the principles for the comparison of a long-lived technology with those with a shorter life span (or possibly with a rival long-lived alternative) even if all the costs were known. What methodology should be employed? We have seen that in the simplest case, the problem comes down to the comparison of a conventional technology with lower unit capital charges but higher operating costs with a long-lived alternative with the opposite characteristics. This comparison is further complicated because long-lived technologies usually take longer to bring into service: this latter factor is important when inflation due to higher oil prices is involved. It would be desirable to deploy a new supply (or perhaps demand control) technology as fast as possible to deal with an oil crisis but the Central Bank may well increase interest rates to restrain the resulting inflationary tendencies in the economy. This response to suddenly higher oil prices is particularly harmful to the choice of a long-lived technology of high unit capital cost requiring a long period of construction. This factor proved to be a major hurdle inhibiting the rapid deployment of the long-lived technologies in the 1970s whether they were nuclear or oil sands installations. The shorter-term choices are favoured though costs may well be greater in the long run.

There is also the degree of risk of technological obsolescence to be considered over the projected life of a half-century or more for a long-lived technology. As electricity itself cannot be improved upon in principle, there is very little risk of its obsolescence. Nevertheless, there is a degree of risk that the present electrical model involving centralized generation and a networked distribution system will be displaced over time with the advent of distributed generation. Houses and factories may have their own power generation facilities that in some cases may also supply thermal energy for heating at high efficiency. This class of uncertainty may be called system risk.

But even if system risk were negligible, how should an individual long-lived facility be evaluated? Classical discount calculations are not very useful for longer than a decade or so in the normal range of percentage rates employed. Such calculations go blind rapidly after five to ten years. This question is especially important in the case of reactors of the CANDU type which could be designed with replaceable components in such a way that the operating life could be extended indefinitely in principle. This option deserves much more study than it receives at present. No solution will be offered here except to note some degree of inflation is still more probable than deflation—central banks now commonly target a range of between 1-3% per year. The best guide may then be a study of the increase expected in the already low operating costs of such facilities over time. If these are not greatly subject to the pressures of gradual inflation, it may be possible to compute a super-maintenance cost function that could be charged against costs to ensure that the facility remains operable over the long time expected. Such a financial provision made over the life of a single facility could be the basis of a revolving fund established to offset the higher initial investment in subsequent units in a deployment sequence.

Without some resolution of this so-called first-cost problem, it will prove difficult to build new long-lived generation facilities at any time but especially in the atmosphere of an emerging crisis in oil supply. In fact, no new nuclear facilities are under construction in North America at present. At the same time, those facilities already built are being operated in preference to other supply units and are even being modified to extend their service lives. This is what is happening in the nuclear industry in the U.S. where the best reactors now generate electricity for an operating cost as little as 1.5 U.S. cents/KWh. Instead, smaller-scale, more flexible and faster-to-build combined-cycle facilities are favoured that convert natural gas to electricity at high efficiency. These units consume a fuel whose price no one can predict over a few months and a major hedging industry is evolving to deal with this problem. This is a major paradox in the energy field.

In the hydraulic field, the question as to how much of the potential of a given power site should be developed is a micro version of the general deployment problem. In the usual case, the unit capital costs increase more than linearly as the full potential of the site is approached. When prevailing interest rates are high, some of the available head of water may be sacrificed to lower the overall average unit investment requirement. Because private companies generally require higher rates of return than public entities, they are more prone to sacrifice some of the potential. But once a site is developed, it is generally difficult to justify re-building to capture the unused head at a later time. This has been the historical experience at the Chaudiere Falls in Ottawa. This facility has been operating some eighty years with a significant underdevelopment of the site, yet successive studies of the feasibility of increasing the height of the dam conducted over the years have been generally negative on cost grounds. Nevertheless, if the site had been re-developed at any time in the past, the investment would have proved attractive in retrospect. Does anyone care how much capital might have been invested had it been done some thirty years ago when the re-building option was last assessed? If this is true over a span of only thirty years, it is doubtful anyone even knows how much was invested all those years ago to build the installation in the first place. Now, public opposition on environmental grounds (even if misplaced) makes such a re-development essentially impossible.

This issue has been explored in some detail here because Canadians have significant experience in both the hydraulic and nuclear generation fields. If the question of the evaluation of the long-lived technologies is left unresolved as it is at present, more expensive options than necessary over the longer term may be deployed in the rush to provide an alternative to the supply of conventional oil. The options with a lower unit capital cost and generally shorter times to first output may be more flexible and timely but their higher long-term costs will have to be borne by someone over the years. It is thus important to identify not only the next best options as the peak is approached in the world production of conventional oil is approached, but their deployment characteristics as well.

The Obstacles to the Rapid Deployment of Technologies or Technological Systems

Even if we were certain as to which technologies to deploy as the peak in world oil production approaches, there is still the question of the factors limiting their maximum rate of deployment. This is the field where the study of system analyses by such groups such as the *IEA Energy Technology System Analysis Project* (ETSAP) is helpful. Before proceeding to the issues involved in the accelerated production of non-conventional oil, we will consider the withdrawal of oil from stationary applications under the influence of higher and more consistent prices.

In the making the decision to `withdraw' or `replace' conventional oil, the need to control carbon dioxide emissions may well play a defining role in the choice of either individual technologies or systems. We have already seen that the low technical cost of conventional oil makes it desirable that all this energy available should be produced on normal economic grounds. A second factor will be considered here. The total world emissions from mobile applications (less than 2.0 gigatonnes carbon per year) are both less now, and are foreseen to remain less in the future, than the sustainable allowable emissions from all the fossil fuels together of about 2.7-2.9 GT C/year given that sustainability is defined as the stabilization of the concentration of this greenhouse gas in the atmosphere. The sustainability objective could thus be met by `withdrawing' the fossil fuels or alternatively capturing their carbon dioxide emissions from non-mobile applications. This approach is now feasible with the advent of processes for the capture and sequestering of carbon dioxide applicable to large point sources such as the generation of electricity from coal. These processes can only be applied to mobile sources with great difficulty although some indirect techniques have been explored for the production of atmospherically-neutral carbon-bearing motor fuels.[16]

Choosing the withdrawal option to concentrate the remaining conventional oil supply on mobile applications has the further advantage of delaying the advent of the peak in the conventional supply dedicated to the transportation sector by a decade or more over a wide range of probable conditions.[17] Moreover, choosing this option does not preclude augmenting the slowly declining post-peak conventional oil supply from non-conventional sources. Nevertheless, the withdrawal option is made more difficult by a major asymmetry in the energy system. Due to its special attributes, oil products penetrate an energy system easily but are more difficult to remove. This 'stickiness' hindering the replacement of conventional oil does not apply to essentially similar products derived from non-conventional sources.

Additional supply derived from the latter sources for oil does share a special problem along with other more costly energy options. These technologies will bear the brunt of a fall in demand during an economic downturn. A small fall in demand will lead to a disproportionate drop in requirement for the output from the newer sources because the technical cost of production of non-conventional oil is generally so much higher than the oil derived from conventional sources. A too-successful deployment of such alternatives will tend to backfire on those promoting them except perhaps in the case of some applications involving the substitution of natural gas for oil in those countries with a surplus of this convenient fuel. This latter problem was clearly recognized in the oil crises of the 1970s with the negotiation of the Minimum Secure Price among members of the International Energy Agency. Unfortunately, this limited degree of protection agreed to protect investors in non-conventional oil production was soon overtaken by events. Because these replacement options are invariably more capital intensive (except for certain options involving natural gas), the provision of this extra investment may prove as important a restraint on the rapid deployment of non-conventional oil options as the technical factors involved. Without some degree of protection, the world may be confronted with a 'stop and go' set of economic signals as has discouraged production from the oil sands over the years. This problem will become more general as the peak is reached and such protection schemes may have to be re-visited to encourage sufficient output for all alternatives to conventional oil including savings on the demand side.

In an age when carbon dioxide emissions should be limited, there are doubts as to whether the production of carbon-bearing non-conventional sources of energy should be encouraged to substitute for conventional oil. In Canada, the answer to this vexing issue may be expected to be pragmatic as it is likely to be in other countries. Natural gas is less carbon intensive than oil and thus should be consumed in its place. Because the production of conventional oil from the Western Canada Sedimentary Basin has been in decline for some years, it may be argued that additional supply from the oil sands merely substitutes for the steady fall in conventional output, at least at present, a position strengthened by the fact that the oil sands occur in the same general geographical region. These arguments should be accepted because the potential for the capture and sequestering of carbon dioxide is the highest in the same region while the incentive for applying these complicated and expensive techniques, both economic and political, is also the greatest.

We have seen that non-conventional oil production may substitute almost seamlessly for conventional oil though careful attention is necessary to such apparently minor factors as the cetane number of diesel fuel derived from the oil sands.

Hybrid Gasoline- and Diesel-Powered Electric Vehicles

Most experts expect a slow but steady transition in the road transport sector first to hybrid gasoline- or diesel-electric systems and then later to fuel cell-powered units. The first hybrid vehicles intended for general use are now marketed by Japanese companies and other manufacturers will soon be offering a range of models equipped in this way. The first fuel cell-equipped vehicles are expected by the 2003-4 model year but large-scale production is not expected until about 2010. The introduction of both these new classes of vehicles is being driven in large measure by environmental concerns arising before the peak in the world production of conventional oil is reached. All-electric vehicles, with their heavy and expensive batteries, are now seen as a niche application though still important for the future.

The hybrid vehicles depend upon gasoline or diesel fuel and are thus still oil dependent though fuel consumption may fall some 15-20% for simple applications of this technology to as much as 50% for more complex systems. It is not clear as yet whether one particular power system will dominate or whether a variety of solutions will evolve to meet the various needs of the different classes of vehicles. In all hybrid vehicle designs, the existing fuel supply system will be used. Should this emerging power system be judged adequate to deal with both the environmental and oil supply problems in the nearer term, the more complex fuel cell-equipped vehicles may not appear in volume until the later decades of this century after the peak in conventional oil production has passed. The inevitable consequence of a successful and widely-adopted hybrid power option for vehicles is that the expansion of non-conventional oil supplies will be steadily required during at least the first half of this century.

The introduction of fuel cells for mobile applications is quite different from the hybrid designs in that a major issue arises in the manner in which vehicles so equipped are to be fuelled. Most cells designed for use on board vehicles require a feed of hydrogen though there is a significant effort underway to allow the direct use of methanol without prior reforming. This alcohol, ethanol and gasoline may also be reformed on board to produce hydrogen so allowing the vehicle to carry the fuel as one or other of these convenient liquids. The successful development of on-board reformers permits the continued use of the existing fuel delivery system because the modifications needed to handle methanol and ethanol in addition to gasoline or diesel fuel are not large.

To supply hydrogen directly, however, requires a new distribution system whether the hydrogen is carried on board cars and other vehicles as a pressurized gas or a cryogenic liquid, or chemically-bound in decomposable hydrides including boron compounds or physically-bound in special carbons tubes of very high surface area as may be produced by the new nanotechnologies. The hydrogen itself may be derived from the reforming of natural gas obtained from conventional sources, from Coal Bed Methane operations, from the gasification of coal or biomass, or from the electrolysis of water. The electrical requirement for the latter option may be generated in a number of ways including by nuclear facilities or integrated with renewable electrical generation in solar and wind installations. In the nuclear field, there is renewed interest in high-temperature pebble-bed nuclear reactors that could heat helium gas to high enough temperatures to provide the thermal requirements for the decomposition of water in certain complex chemical cycles. This approach avoids the losses inherent in the Carnot Cycle which limits the maximum possible conversion of thermal energy to electricity.

The future evolution of the electrical network is also a major issue for the supply of hydrogen to vehicles. It is quite possible to electrolyze water in homes to produce hydrogen in equipment that is commercially available at present though there are questions concerning the supporting compression and storage stages required. This route implies an additional load on the network though off-peak generation for most of this production may be feasible. Electrolysis at home implies the continuation of the present system of centralized generation with the further advantage that the electrical supply network could be expanded incrementally to meet this additional load. There is the disadvantage of very few if any applications for the inevitable associated oxygen production.

Alternatively, the electricity could be provided from stationary fuel cells installed to meet both the electrical and thermal needs of the home or groups of homes at fairly high total conversion efficiency. Natural gas would be the usual fuel. In some of the schemes now in the trial phase, it is possible natural gas could be reformed or reacted in a stationary cell in such a way that a stream of hydrogen of high purity could be separated to fuel the cells mounted in vehicles. A membrane of palladium might be used as the separating medium. Microturbines working alone or in combination with fuel cells are another such option based upon natural gas. These latter options imply a major expansion of the natural gas distribution system beyond the foreseeable supplies of conventional natural gas available in North America.

There is another uncertainty should fuel cell-powered vehicles be widely adopted. The efficiency of the conversion of hydrogen to electricity in fuel cells is not a strong function of scale in that small cells do almost as well as larger ones. Because most cars are parked a significant fraction of the time, the expensive fuel cell in which the capital investment has already been sunk is also idle. Unlike the present gasoline-based engine power plants, it is relatively easy to connect the fuel cell to meet other electrical needs. Fuel cell-equipped cars or trucks could well become a source of electricity for remote cottages and back-up power for emergencies such as ice storms, etc. In effect, the house would be plugged into the car. This possibility is thus diametrically opposite to the production of hydrogen by the electrolysis of water from electricity delivered to the home from the grid.

In the rapid deployment of fuel cell vehicles, there is significant system risk in backing one or other of the options for the production, delivery and carriage of hydrogen. There is even the possibility that options of opposing characteristics may be deployed at the same time depending upon local circumstances.

The peripheral issues arising in the rapid deployment of vehicles equipped with fuel cells also require attention. For example, there is the question as to whether the resources of precious metals such as platinum or palladium are adequate at present price levels, and whether more abundant substitutes can be found in time. This problem could be offset in part by designing the fuel cells in such a way that the precious metals could be readily recovered at the end of their normal service lives much as these valuable metals are recovered now by charging obsolete computer equipment into copper smelting facilities. One Canadian smelting company is a leader in the latter field.

In summary, the key issue is how to power the world's growing fleet of vehicles and at the same time reduce total carbon dioxide emissions after the peak in conventional oil production has past. The on-board fuel cell is an important option because of its inherently high efficiency of energy conversion. In Canada, there is the intriguing possibility of providing the hydrogen from the methane whose release is promoted from coal seams by the very action of sequestering captured carbon dioxide in the coal.

This technology is of interest in Alberta and possibly other regions with large unmineable or unwanted coal resources. The release of each mole of methane requires at least two moles of carbon dioxide to be sequestered in the coal. Hydrogen can be produced from this methane in conventional reforming processes equipped to capture carbon dioxide so there are no net emissions of this gas to the atmosphere when the hydrogen is consumed as a fuel whether to power vehicles or for other purposes.[18] The available resource of Coal Bed Methane is substantial and it should not be too long before much more is known of the practicality of this possibility. It is noteworthy that the U.S. already produces some seven percent of its natural gas output from this non-conventional source though there are only trial operations underway involving enhanced production with concurrent carbon dioxide sequestration at the present time.

Due to the higher cost of transporting hydrogen by pipeline as compared to natural gas, hydrogen might be obtained from renewable or nuclear sources in Central Canada or other regions via gasification or electrolysis processes. Geography may be determining as it has been so often in Canada's economic history.

It is not possible to say at the present time which of these approaches for the supply of hydrogen should be deployed. Nor is the associated maximum rate of deployment known for each case with any certainty. Each choice faces both its own internal technical risk and a significant systems risk. The worst outcome would be if the confusion caused by the competing claims of the various options seriously delays the preparations needed for their launching.

Conclusion

Before the peak in conventional world production is reached, the oil supply system is seriously out of internal equilibrium because large quantities of more costly oil are being produced though less costly supplies are available from large fields ready for production located mainly in the Middle East. This unstable inverse supply behavior has persisted for nearly the last three decades. Because of its importance, oil influences the rest of the energy economy as a whole so that it too is sufficiently out of internal equilibrium most of the time that the general equilibrium theory of the economist provides only a poor representation of the actual working of the field. Only during periods of weak demand in recessions and other economic downturns does the energy system approach a quasi-equilibrium state.

The unstable nature of this non-equilibrium state is the explanation for the wide swings in prices experienced with changing economic conditions even though consumption changes only so slightly that on a per capita basis, it has been effectively a constant for nearly two decades. On general systems engineering grounds, price swings may be expected to increase in frequency and amplitude as the peak in conventional production is approached. Using discounting calculations at the usual range of rates, the peak in world production should be detected by trading markets about ten years before. Thus the peak in world production predicted to occur in the 2017-2020 period by the parabolic projection of the Mean Case of the U.S. Geological Survey should be evident by at least 2010. There is time for at least two periods of low oil prices before this latter date. Such periods of low prices discourage the development of such capital-intensive alternate sources as the oil sands of Alberta.

Although prices will be generally higher, the energy system will behave more rationally after the peak has passed. There is no longer any reason for the present unstable inverse supply pricing practice to persist. Lower cost sources will tend to be consumed first. Demand will still be rising albeit more slowly. The flexibility and resilience of the liquid fuel supply will be much reduced as supply comes increasingly from non-conventional sources.

Though the end of inverse pricing will tend to return the energy system to internal equilibrium, another problem may be expected to arise but from a very different cause. It may not be possible to increase the supply of liquid fuels fast enough to meet the needs for the mobile consumption of energy. If the non-conventional sources of hydrocarbon liquids cannot be produced in sufficient quantity in minimum-cost sequence, the energy system will once again enter a non-equilibrium condition. Higher-cost sources will be developed simultaneously out-of-turn along with lower-cost supplies. A return to an unstable situation is probable because the supply of liquid fuels derived from non-conventional sources may well prove limited by the maximum rate of deployment of the necessary facilities due to their high cost and complexity. These are unlikely to be built rapidly enough unless operators are given guarantees of one kind or another given the many uncertainties.

The main object of energy policy should be to operate the energy system as close to internal equilibrium conditions as possible. Lowest cost sources should be used first. This is best achieved by addressing deployment issues as soon as possible given a peak forecast to occur as soon as 2017-20. In particular, there is a need to examine the nature of deployment-limited production in the context of the long-lived technologies. Otherwise, with all the problems that may be expected to arise, there will be a natural tendency to turn to options that could provide supply first. This issue is important as these may not necessarily be the best long-range choices on either cost or environmental grounds.

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NOTE: This paper may be found on the Web at pages.ca.inter.net/~jhwalsh/pastpeak.pdf.

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