The Plug-In Hybrid Electric Vehicle, Nuclear Energy and the Hydrogen Economy

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This presentation is based upon the paper *The Introduction of Plug-In Hybrid Electric Vehicles and the Evolution of the Electrical Network Towards the Hydrogen Economy* that appeared in the Proceedings of the Canadian Association for the Club of Rome, Series **3**/Number 11, 2007. It may be found at the CACOR Web Site (www.cacor.ca) and is also mounted at the author's personal Web Site at http://pages.ca.inter.net/~jhwalsh/wphevhy.html. These Speaking Notes were based upon the original paper whose text was written in October of 2007 and updated in February of 2008.

This presentation stresses the opportunities open to Ontario which faces some difficult choices in the energy field. Nuclear power becomes even more important to the province when a large new load is placed upon the electrical network arising from the rapid deployment of electrically-powered vehicles. Taking the wrong road now will weigh heavily on its future. Not so clear is the effect of this new load on the evolution of the network over time nor how it should be managed. To illuminate some of these issues, the reader is asked to imagine himself transported to the central control room of this very large electrical network to watch the dials as the chain of events unfolds over the next two or three decades given the successful introduction of electric vehicles. In presenting what is essentially another scenario for this period, it is worth noting that on 14 February 2008 the Shell Oil Company announced two new possible views of the future arising from their studies entitled *Scramble* and *Blueprints*; these titles refer to an almost every man for himself situation in the first to success in achieving at least a modicum of international cooperation in the second. It is especially interesting that the company's new scenarios imply conventional oil production will peak around 2015.

Success in the development of a workable lithium-ion or other batteries of equivalent performance is assumed in this scenario. At this time, it is not yet certain sufficient progress will be made to justify a widespread plug-in hybrid option in the near future, but, based upon the steady of advances announced in what seems every passing week, the outlook for electric vehicles appears to be improving rapidly as time passes. The odds at the time of preparation of this text seem better than 1:1 and may be as high as 2:1 but perhaps no higher. I am particularly pleased that a substantial contribution to the current advances in lithium-ion battery technology was made by Professor Chiang in my old Department at MIT. There has long been Canadian interest in this class of battery with a manufacturer in Vancouver, and efforts by several organizations, particularly Hydro-Quebec, to develop both the battery and drive-train aspects of electric vehicles. There are two small Canadian companies offering low-powered electrical runabouts at present. The development of superior and safe lithium-ion batteries for vehicles is greatly aided by the steady progression of market applications ranging from the small units now used in laptop computers and other portable electronic devices, to the larger units being introduced to power autonomous power tools and robots, and the still larger batteries required for golf carts and the like.

Why is there such great interest in Plug-In Hybrid Electric Vehicles (PHEVs)? An all-electric vehicle would be the ideal solution and there are those who strongly support this view but the Plug-In Hybrid promises a reasonable compromise that may be ready for deployment very soon buttressed by the following four statistics:

- Over 90% of the energy requirements of the transportation sector are derived from oil and, although the subject remains controversial, the peak in the world production of oil from conventional sources is likely to occur sometime in the period 2010-2025;
- Developed economies devote something approaching 70% of their total oil consumption to the transportation sector (69% in the case of the U.S. in 2006), and France reports a slightly higher percentage because of the great importance of nuclear energy in its economy (about 78% of total generation);
- World oil consumption accounted for 41.3% of the emissions of carbon dioxide from the fossil fuels in 2006; and
- Most cars are driven much of the time for short, local trips. In the U.S., General Motors Corporation has conducted market studies in preparation for the launch of its *Volt* plug-in series-type hybrid, in which it was found that 78% of the commuters drove 64.5 km (40 miles) or less to work. According to the 2006 Census, employed people 15 years or older in the Ottawa-Gatineau region travelled a median 8.1 km to work by whatever means.

Because this presentation concerns the impact of a large emerging new load on the electrical system, it seems appropriate to note other major load changes that are likely to occur over the same period of time. The network may be relieved of a share of its lighting load as a result of the present efforts to introduce Compact Fluorescent Lights (CFLs) more widely, and, given the successful development of white light of better characteristics, by the later introduction of Light Emitting Diodes (LEDs). This change will tend to reduce the load in the evenings and thus may widen the time available for charging the PHEV vehicles off-peak. On the other hand, with greater emphasis on good insulation practices and better building design generally combined with the greater application of ground source heat pumps and the like, more of the electricity generated may be directed to space conditioning in the future. The major electrical requirements of desalination plants may also be a growing market in some dry regions such as California particularly as membrane technology matures.

The Plug-In approach is unusual among the new energy technology options becoming available in that it does not require major capital expenditures immediately on the part of the utilities and can be profitable right from the start. This is because sufficient capacity exists at present to support the off-peak charging of a large number of vehicles for several more years into their deployment. The large capital expenditures needed for new generating facilities and the upgrading of the transmission system come later but this requirement may be both predictable and spread relatively smoothly over time. As far as the network aspects are concerned, it is difficult to find any other option that requires so few changes in policy, so little new technological development and testing, or so short a period of introductory trials for its perfection. From a policy point of view, no new controversial financial incentives are necessary because there is no road tax at present on the electricity that would be consumed in these vehicles; an already large economic driving force is already in place. With success in the introduction of large numbers of electric cars, this loss in revenue would have to be replaced sometime in the future, but by then there may be other more sophisticated ways of raising the funds needed for roads such as by the intelligent imposition of congestion taxes. This combination of advantages is remarkable indeed. Nevertheless, the number of PHEV vehicles is unlikely to increase so rapidly that there would be insufficient time to install new capacity directed to meeting their needs.

California is very important to the development of this class of vehicle. The climate is mild and so friendly to batteries; the highly populated regions are generally flat. There are many rich people who would not be greatly concerned about breaking original manufacturer's warranties but who have little patience with hassles. The cars must work. This attitude, when matched with the careful, steady development characteristic of Japanese manufacturers, is a guarantee of progress. Moreover, original manufacturers may well sell early PHEV models with the battery system leased to the buyer. This would allow a reduction in the purchase price of the car with the main technical risk (the failure of the battery) assumed directly by the manufacturer rather than indirectly through warranties as at present. From the buyer's point of view, the monthly bill for leasing the battery system would be compensated by the lower running cost arising from the use of electricity rather than gasoline over the same period of time. A lease option of this kind would be another incentive to operate the car as much as possible in all-electric mode.

There are a number of small companies in the State now offering, or soon will offer, kits to convert the existing hybrid models to the plug-in option. One such company offers a nickel-metal hydride battery unit with related software that could itself be converted to high-performance lithium-ion technology as they become available later. This change would effectively double the all-electric range. There are companies interested in this field in Ontario as well who may be offering conversion kits soon. The typical extra battery capacity installed in these conversions allows an additional charge of some 5 kWH, but, of course, this is measured from bottom to full charge. As shown later, this is the effective equivalent of about one litre of gasoline (perhaps more) suggesting an all-electric range probably around seven to ten km. This distance is confirmed by some of the press statements from the Toyoto Company who will start street trials of their own plug-in version of the *Prius* parallel hybrid this year.

In still another trial, the Google Company, led by its famous Russian, Sergey Brin, has begun a $10 million program to encourage the introduction of electric vehicles. As part of this activity, the company has acquired six PHEVs, five of which will be assessed in the usual way by routine trials by employees driving to work. The local power utility will be involved in a trial of WiFi control of the sixth car. It is envisioned that the charging process could be stopped and re-started as needed by electronic signal, and that, in later trials, the possibility of returning energy to the grid from the car on receipt of another signal would be assessed. Owners of these cars would presumably enter a contract for electrical supply that requires them to keep their vehicles plugged in whenever possible. In Canada, people are already accustomed to plugging in their cars during cold weather to power engine block heaters and sometimes small electric space heaters as well. In cold cities such as Edmonton, it is commonplace to provide electrical outlets for the use of employees. Battery warmers and electric space heaters may well be installed in PHEVs in cold climates and operated during plugged-in periods.

It is quite possible to envision one million or so PHEVs under contract in the Bay Area of California in the future. At off-peak periods when the cars are charging, should serious problems arise as when a large nuclear station trips out (two reactors shut down in the same period in Florida during a local power crisis in February 2008), perhaps one GW of load from the PHEVs could be dropped at a touch of a button. On the other hand, charging could be resumed even during peak periods if for any reason additional power becomes unexpectedly available as it could when there is significant but unpredictable generation from the wind. But most important of all, if there were trouble with excessive loads during the peak period– a not unusual situation in either California or Ontario during the summer– perhaps as much as one GW could be supplied back to the grid from the vehicles themselves if only for a short period of time. This supply would also have the advantage of being geographically well dispersed around the region. The ability to provide small quantities of electricity for an extended period of time (even if it involves running the engine) could also be important in Canada: in the last ice storm, many houses would have had heat if their cars could have supplied sufficient electricity to allow the operation of natural gas or oil-fired furnaces. There are those who believe that this technique would allow remote cottages to enjoy power as soon as the occupants arrive in cars so equipped.

Careful consideration is necessary to the planning of the contractual arrangements between the power company and its individual customers. The ideal situation is one in which each car has its own identifying account; cell phone technology could be used to add monitoring of the electrical consumption (with occasional exports back to the grid) regardless of the location of the PHEV. It is also important to encourage the provision of outlets by third parties such as employers, and the operators of parking lots, shopping malls, arenas and clubs, and the like. This might be done with the use of the radio frequency identification (RFID) tags now used by department stores to discourage shoplifting. When a car is plugged-in to a third party outlet, the host supplier of the power would be identified as well as the car. It then becomes possible to bill the quantity of electricity consumed while plugged-in directly to the car's account since this information is transmitted independently from the car to the centralized computer. The third-party host is relieved of this cost because the computer could simply deduct this quantity of electricity from that measured at his meter. Measures such as this to encourage the number of outlets available to PHEVs require such innovative systems for billing users away from their home base. Given success with such schemes with improvements in the control, metering and billing of electric vehicles, it becomes possible to devise techniques to in effect add significant storage capacity to the electric network. This would allow the introduction of new nuclear reactors sooner than otherwise would be the case as a means of coping with their large unit sizes and inflexible operational characteristics. The power company could provide incentives in the form of discounts to power bills to encourage PHEV owners to enter into such arrangements with the aim of increasing the time the car is kept connected, say 300 to 350 hours a month, to earn reduced charges. Reductions in rates could also be provided to those who offer to be major connecting hosts such as shopping malls or large employers.

The Electrical Network

At the end of 2006, Canada's total installed generating capacity was 123 GW. The corresponding generation that year was 353 TWH. For the country as a whole, hydropower, thermal and nuclear generating facilities accounted for some 60, 24 and 16 respectively of the total. However, this breakdown gives a misleading picture of the regional situation obtaining in any one province. British Columbia and Quebec rely heavily on hydropower; Alberta, Saskatchewan and parts of the Atlantic Provinces rely to varying extents on the fossil fuels; and Ontario is supplied from a mix of hydropower, nuclear reactors (which typically account for some 50% of the electrical energy) and generation from coal from conventional facilities, although this latter source is being phased-out over time as a matter of policy. A major distinguishing feature of the Canadian electrical system is its close integration with the very large electrical systems to the immediate south in the U.S.A. as opposed to east-west linkages across the country although these are being strengthened.

The most expensive electricity is that one does not have. The art of the management of the network is to maintain supply in a complex system that has no effective storage capacity. A central theme of this paper deals with the need to keep the network stable as the electrical load rises from the introduction of an increasing number of electrically-powered cars at the same time other markets are growing. Fortunately the increase due to the deployment of electrical vehicles may be both gradual and relatively predictable. It is true, however, that the first large-scale Sodium/Sulphur fuel cells have been put into service in the U.S. for storage purposes; there is also a Canadian proposal that shows promise as a storage device based upon the use of flow-type batteries which operate on the principle of changing the valence state of vanadium ions in water solutions. Even limited storage would help with the control problem, but no allowance is made for this possibility here. Rather, the electrical network is assumed to stay much as it is now at least during the early stages of the introduction of PHEVs and other electrical vehicles more generally. Only later, with much greater loads in an era of the high-speed charging of batteries, will substantial and costly changes be necessary to the distribution system. Charging rates will be assumed to be only a modest one kW or so though two kW (or even more in some cases) rates may be quite feasible with the network as it is at present, depending upon the local concentration of these vehicles. The time available for overnight charging will be taken as a full ten hours with the result the typical energy transferred would total about 10 kWH. (There may be other opportunities during the day to recharge off-peak but the energy transferred to each vehicle over a twenty-four hour period will be assumed to be the same 10 kWH.) A million cars charging at the rate of one kW represents one GW additional off-peak load and an energy requirement of ten kWH per day per vehicle amounts to 3.65 TWH on the year. It is possible this number of plug-in cars could be accommodated in Ontario alone before major problems arise.

This situation is remarkable in that almost no additional capital expenditure is necessary for both the network and the main generating facilities during this early phase as the new electric vehicles are being introduced; this is the opposite of the situation confronting the introduction of most new energy technologies. The additional energy required must come from somewhere - most likely by some combination of additional wind capacity and more service hours for the existing fossil-fired facilities while waiting for additional nuclear capacity to be commissioned. Carbon dioxide emissions from generation would thus be expected to rise in this early period but perhaps not much on an overall basis when those from the conventional cars displaced are deducted.

The electrical network may be thought of as the link between major generation at its core and a diverse market at its perimeter. There will be increasing decentralized generation over the years as well at the perimeter. This may take the form of solar panels and mini wind turbines mounted in houses and other small establishments, and co-generation based upon natural gas consumed directly in mini-turbine and reciprocating engines, and indirectly in domestic hydrogen fuel cells. In the co-generation case, the thermal energy component would be devoted to heating space and water though a Japanese company has recently announced a fuel cell system from which a side stream of hydrogen may be diverted to power fuel cell-equipped vehicles in the home. Of particular importance are the small reciprocating generators that were introduced into the New England market this winter season. The object of much of this effort is to operate the house autonomously by making the link to the grid unnecessary. However, the connection to the grid becomes more important than ever to smooth-out the contribution of this **distributed** generation when the new load from the electric vehicles must be met. Solar panels will not supply energy during the night when the PHEVs are most likely to be plugged-in; the availability of wind-generated power depends on wind conditions; and it may be that co-generation units based upon natural gas will be operated less at night than during the day because less heat is needed when thermostats are turned down. The grid provides a cheaper alternative than expensive and troublesome local storage in batteries. It is an important conclusion of this paper that the advent of the PHEV makes disconnected generation no longer viable because of the increased demand for energy necessary at the individual household or neighbourhood level.

Generation at the core of the electrical system is considered here simply at three distinct levels: base load; shoulder load; and peak load. In an Ontario context, nuclear generation is the major contributor to base load requirements in the future with reactors individually sized at about one GW capacity. New base load capacity is thus brought on line in major increments. New generation from coal is confined to individual units of about 500 MWe capacity equipped to capture and sequester carbon dioxide. These units are installed primarily to meet shoulder loads but also to fill base load requirements arising from the gaps between the commissioning large nuclear reactors. Peak loads are met increasingly by natural gas-fired combined cycle facilities which are displaced ultimately by hydrogen-fired turbines.

Special attention is required to the rapidly expanding generation from the wind. Total world nameplate capacity grew about 20 GW in 2007 to reach a remarkable 94.1 GW at the end of 2007; by March of 2008, the total capacity had reached about 100 GW. This may be compared with the world nuclear capacity of 372 GW at the end of November 2007 though of course the service hours of the reactors is much greater. The U.S.A. added 5.26 GW alone for an increase of 45% on the year with Texas the lead state. The European Union grew its wind capacity 25.5 GW to reach 67 GW. Germany remained the largest generator with Denmark the most reliant on this form of renewable energy (about 20% of total generation in 2006). At the end of 2006, Canada ranked 12th in capacity at 1.46 GW. Proponents suggest wind generation can realize 30% of nameplate capacity over the year, but experience to date suggests that the actual figure is in the range of 20-25%. It appears difficult to obtain more than 25% of total generation from variable wind sources in most networks. Wind turbines are self-dispatching but can always be turned off. Wind energy shares with nuclear energy a low (in fact zero in the case of wind) fuel cost and a relatively high unit capital cost. Otherwise the main technical characteristics are the opposite: supply comes from a large number of small units that may be installed relatively rapidly but operate unpredictably.

There are two links between wind generation and electric vehicles. As with any other major new load, PHEVs may increase demand sufficiently to justify further interconnections to increase the utility's footprint; this may be achieved by the increasing use of high-voltage DC transmission lines. Serving a larger area may be expected to allow the wind turbines to operate more of the time since their intermittent supply is smoothed out over a larger region. The second link concerns the degree of control of when and where electric vehicles can re-charge. If a large number of vehicles are plugged-in during the peak demand period, the wireless control system can prevent the re-charging of the battery. Nevertheless, should wind power become unexpectedly available, this flow could be allowed to resume instantly given a workable wireless electronic control system. There is thus another tool emerging to even out the contribution from the wind.

The First Stage

A few models of hybrid-only vehicles are now available and more will be marketed next year. No PHEVs are yet sold by the traditional manufacturers to date but the first may become available soon. There are now third party companies mostly in California that offer kits to convert some of these models, especially the Toyoto *Prius*, to plug-in operation and there may now be Canadian companies active in this field. The Toyoto Company will begin street testing its own adaption of the *Prius* to plug-in operation this year in Japan.

At present, the extra cost of a vehicle in hybrid form in the U.S. is about $ 5000 above the equivalent all gasoline-powered conventional model. The cost of its conversion to plug-in operation is about another $ 5000 for rather limited performance. The immediate objective of most manufacturers is to reduce these extra costs to some + $ 3000 and + $ 3000 respectively and increase the range of all-electric operations. The present conversions generally offer only about another five kWH of battery capacity.

As far as operating costs are concerned, it is convenient to convert electrical energy to `effective ' litres of gasoline. On the basis of the First Law of Thermodynamics, a typical overnight slow charge of 10 kWH from the existing network is the energy equivalent of approximately one litre of gasoline. However, when gasoline is used to power an engine, there are unavoidable losses associated with the restrictions of the Second Law thermal energy-to-work cycle to which must be added many practical leakages of energy. Conventional cars generally convert gasoline in the tank to work at the wheels at less than 20% efficiency; typical values may range from 13-15% depending upon how accessories are handled in the calculation.

Nevertheless, there are also inevitable losses incurred in the battery/electrical power train. There are losses in the transformer, in converting to direct current, in charging the battery and recovering energy from it, as well as in the control system. These must be added to the normal losses in the motor and drive train. Here, in the absence of better information, it will be assumed that 5 kWH is effectively equivalent to one litre of gasoline; if this value proves too high and the correct value is nearer 4 kWH, all the better. Based upon a battery size of 5 kWH rated from bottom to maximum charge from which half the swing in the theoretical energy total could be withdrawn in a practical case before re-charging (with 2.5 kWH taken as operationally equivalent to 0.5 litres), the car could go seven to ten kilometres in all-electric mode. This limited range seems approximately correct when compared with estimates deduced from press information released by the Toyoto Company in reference to the introduction of its new plug-in *Prius* model. On this basis, with the current pricing of gasoline and electricity in the Ottawa region, the cost comparison would be $1.05 or so for a litre of gasoline to 42 cents for the electricity to travel the same distance. The gasoline price includes about 30 cents tax, so an economic comparison would be roughly 75 versus 42 cents. The impending widespread installation of Smart Meters in Ontario would result in higher electrical prices at peak periods and lower ones at night.

The Second Stage

At some point, probably after there are a million PHEVs in routine service, extra generating capacity will be required over that normally anticipated. The local distribution network would also have to be strengthened, particularly if faster charging techniques were developed as would be required if an economic capacitor were developed employing the new materials emerging from nanotechnology. Though large capital expenditures would be needed, this requirement would be ameliorated to some degree in that the new investment would be gradual and incremental.

As far as new generating capacity is concerned, the growth in the electrical load will be flatter due to both off-peak charging and the introduction of improved means of electronic control of the increasing number of electric vehicles. It thus becomes possible to commit to the large incremental blocks of capacity characteristic of nuclear energy sooner than otherwise would be given the steady and predictable growth. This is an important advantage for nuclear power.

To meet the shoulder load, and also to fill in the gaps in service dates between the commissioning of the large individual increments of nuclear power installed to meet the base load, this author favours the coal/oxygen combustion system with its relative ease of capture of carbon dioxide for subsequent sequestration. Small units are being built at Schwartze Pumpe in eastern Germany with lignite as the fuel by the Swedish power company Vattenfall (30 MWe with service to begin in mid-2008; this demonstration-scale project is apparently under the personal patronage of the Chancellor, Angela Merkel), and in Queensland in Australia. Saskatchewan Power Corporation and other members of the consortium formed to promote this technology put their plans to build a 300 MWe unit of this type at the Shand Generating Station in abeyance, but this was a rather ambitious project for a relatively small utility. Nevertheless, $ 240 million is provided in the federal budget of 26 February 2008 to a third party trust to continue such efforts contingent on support from the province. Interesting testing of a burner of vertical axis design is underway in the Natural Resources Canada Laboratory at Bell's Corners in the outskirts of Ottawa. The high flame temperature resulting from the use of oxygen is normally held within acceptable limits by mixing with a re-circulated stream of a portion of the cooled product flue gases. This flue gas has only two major constituents – carbon dioxide and water vapour - so the greenhouse gas may be simply and economically separated by drying. The oxy/coal approach is tolerant of a range of coals of different characteristics and uses more-or-less standard pulverized coal combustion technology. It is claimed that existing air-fired pulverized coal facilities can be converted to this mode of operation. Another important advantage is that this combustion system should require no additional time for dispatch as compared to a conventional pulverized-fired unit in comparable service. The extra cost for the oxygen together with that arising from the new capture and sequestering stages (including provision for the extra coal that must be burnt because of the lower overall efficiency as compared to conventional practice) is estimated at about +3 cents/kWH at the 500 MWe scale. The objective is to reduce this extra cost to +2.5 cents/kWH over time. Comparison studies of these coal-burning technologies are conducted by the *IEA Greenhouse Gas R and D Programme* at Stoke Orchard in England of which Canada is a founding member.

The choice of oxy/fuel combustion technology influences the adoption of electrolysis as a method of producing hydrogen at a later time. This is because these combustion units offer an outlet for the co-product oxygen provided that the electrolysis plant is located close enough to make pipelining of this gas economically feasible.

The cost for the pipelining of carbon dioxide as a supercritical liquid to the geological storage formation (often a saline reservoir or a depleted natural gas field) and for its long-term storage underground is dependent on scale. A single 500 MWe generating station would barely contribute enough carbon dioxide to keep the added costs of transport and sequestering in the most economical range. There is thus a case for multi-industry complexes to be served by the pipeline to the sequestering site. Given that such industries could be located close enough to the generating station in the complex, those dependent upon coal, such as the steel and cement industries, could capture some fraction of their carbon dioxide emissions for joint sequestering in a single facility on a toll basis. All such industries may share a need for access to the Great Lakes.

There is a major sequestering operation underway at the Weyburn/Midale fields in Saskatchewan for the enhanced recovery of oil from mature reservoirs, and others are planned in western Canada. The carbon dioxide required for this procedure is captured from the only synthetic natural gas (SNG) plant based upon coal now operating and this gas is pipelined from the plant location in North Dakota. In Alberta, `acid gas', a mixture of carbon dioxide and hydrogen sulphide originating at sour gas processing facilities, has been routinely disposed of underground for many years. The public discussion of the feasibility of the prospects for the capture and sequestering of carbon dioxide is reminiscent of the controversy surrounding radioactive waste management.

The Third Stage

The production of hydrogen on a large scale is assumed to begin in the third stage to coincide with the deployment of appreciable numbers of fuel cell-equipped vehicles. In the introductory period before that, in the case of Ontario, smaller quantities of hydrogen could be supplied from oil refineries and petrochemical facilities in Sarnia and along Lake Erie, and also could be derived from the coke oven gas (~50% hydrogen) produced now at two steel plants in Hamilton, one in Sault Ste. Marie and another along the shores of Lake Erie. (A hydrogen plant based on coke oven gas actually operated for some years at a steel plant in Hamilton in the 1960s and, given success with the development of the new membranes which will reduce the costs of separation of this gas from this source, this option is likely to be revived). There is also a Canadian manufacturer of electrolysis equipment of long standing in the Toronto area. Nevertheless, hydrogen is generally produced by the reforming of the methane contained in natural gas and, if natural gas costs remain at acceptable levels, this method will probably remain the option of choice. At least two-thirds of the carbon entering this process with the natural gas feed (some experts believe up to 80%) may be sequestered readily since it must be separated in any case: only the costs of capture (as opposed to its release to the air as at present) and for the subsequent underground storage step are additive. As North America reaches its peak production from conventional sources, the resulting higher prices may justify new supplies from the Arctic (Mackenzie Valley pipeline), from imports in cryogenic tankers in liquid form (LNG) particularly in eastern Canada, and from the drainage of methane from coal seams. There is wild card in that new techniques for working the large quantities of methane known to exist in shale formations in north-eastern B.C., Alberta and even eastern Canada, are looking promising. This latter possible new source is as yet little understood.

There is also the possibility of producing hydrogen from Municipal Solid Waste. The demonstration-scale plant at the Trail Road waste dump in the outskirts of Ottawa involves the production of a fuel gas resulting from the rapid heating of the MSW in an electrically-powered plasma device. It is intended at present to generate electricity from the product gas. Nevertheless, it contains hydrogen which could be recovered separately by employing the new membranes or by applying classical technologies such as cryogenic separation. This author has proposed an alternative method by applying a 19th Century technique – coking with hot sand. In essence, a fuel gas is produced by pouring hot sand over MSW from which hydrogen could be separated. The residual hydrogen-depleted gas would then be combusted in air to re-heat the recovered sand to close the thermal cycle.

With these various sources available, there would seem to be ample opportunity to supply hydrogen at acceptable costs for at least the early days of such an option for transportation purposes in Ontario from a number of reasonably geographically dispersed locations.

With success with the fuel cell option, much larger quantities of hydrogen would be required. It is envisioned that electrolysis facilities would be introduced at two levels: local neighbourhood facilities perhaps located in existing service stations (possibly even in the home) from which the by-product oxygen is not likely to find a market. Later, large-scale centralized facilities would be located along the Great Lakes to provide this gas not only for transportation purposes but for use in industrial complexes involving steel plants and other heavy industries. It is noteworthy that the two Hamilton steel plants share a common fence. Processes for the reduction of rich iron ore concentrates (which may be readily produced in the Quebec/Labrador iron fields) have already operated at the industrial scale. The oxygen by-product from the large facilities in industrial complexes would no doubt find a number of smaller specialized uses but the main application would be to support the oxy-fuel combustion of the new coal generating facilities dedicated to meeting shoulder loads. Whether in a few large centralized facilities or many small local ones, the electrical load arising from the electrolysis process could be dropped in an instant to meet the control requirements of the network as necessary, although this may not be the best way of shutting down these plants.

There are many advances in the conventional electrolysis process underway around the world. To give an example, the General Electric Company has found a new plastic suitable for the repetitive cell components which could be mass produced at reduced costs. To replace the expensive platinum usually used for the electrodes, the company has developed nano-scale nickel-based alloys. High Temperature Gas Cooled Reactors would no doubt become an option by this time to supply thermal energy directly to chemical water-splitting cycles for hydrogen production. This route to hydrogen has the advantage that a Carnot Cycle limitation is avoided but it is also true that helium – the heat-transfer gas normally employed - is becoming scarce.

The Fourth Stage

In the fourth stage, hydrogen would be produced from coal by a modification of the emerging Integrated Gasification Combined Cycle (IGCC) process. About half a dozen IGCC plants are in service, or near service, around the world and many more are in the planning stage. In this technology, coal is gasified usually by partial combustion in oxygen; the resulting cleaned and purified fuel gas serves as feed to a gas turbine in a combined cycle of some kind to recover energy from the exhaust gases to generate additional electrical energy in steam turbines. To produce hydrogen or even liquid fuels, processing stages are added to convert the carbon monoxide in the fuel gas to the dioxide (the so-called `shifting' stage with steam) with the concurrent production of additional hydrogen. The total carbon dioxide is then separated for sequestering. Unfortunately, the gasification process tends to be more selective in its coal requirements than most combustion processes. The recent cancellation of the fully-featured *FutureGen* demonstration plant intended to be built in Illinois should not be considered a lack of confidence in this technology but the reverse: it was no longer thought necessary to demonstrate the standard overall IGCC approach. Instead, the funds will be concentrated on the shifting stage that produces additional hydrogen together with the related processes required to separate the carbon dioxide and its subsequent sequestering. Nevertheless, the development problems are such that the IGCC option to produce hydrogen from coal is left to this fourth stage given the continuing competition from the rival natural gas–based reforming option.

Most coal-to-hydrogen conversion facilities require oxygen and, in the case of Ontario, access to the Great Lakes. As in the case of oxy/fuel combustion technology, these plants might well be built in close proximity to a large-scale electrolysis plant for best use of the by-product oxygen. The importance of the adoption of this technology is that it provides a workable way of using coal to meet peak loads on the grid. This may be done simply by diverting some of the hydrogen production to gas turbines for generation as required at peak times. The dispatch time for these turbines should be no different from that of the standard natural gas-fired combined cycle plants now employed for this purpose. Current natural gas contracts with pipeline companies indicate that this is about five minutes. Hydrogen might replace the natural gas in existing turbine facilities in whole or in part though there have been reports of problems arising from this substitution in large-scale turbines. However, two large-scale generation facilities based on hydrogen alone have recently been proposed: one located at Peterhead north of Aberdeen in Scotland (though this project is now abeyance for other reasons) and the other in the Los Angeles Basin in the U.S.A. Both these projects were intended to provide carbon dioxide for enhanced oil production with the hydrogen provided by the conventional reforming of natural gas in facilities equipped for the capture of carbon dioxide in the first case and derived from the gasification of petroleum coke in the other. These projects suggest that problems arising from the substitution of hydrogen for natural gas in gas turbines, if they ever existed, are considered resolved.

With the adoption of continuously operating coal-to hydrogen processes, additional hydrogen could be produced to meet the needs of a growing fleet of fuel cell-equipped vehicles in off-peak periods and to provide an environmentally acceptable fuel for gas turbines devoted to electrical generation at peak times.

Conclusion

The widespread introduction of plug-in hybrid electric vehicles (PHEVs) provides a new approach to the reduction in the emissions of greenhouse gases and to deal with the difficulties anticipated from the impending peak in the world production of conventional oil. There is a major role for nuclear power to provide the base load supply of electrical power essential for this option; in fact, it is hard to visualize any solution that does not require this form of energy. Good use of the emerging information technologies is also important for the optimal management of the electrical network because it must cope with the additional demand from this new class of vehicles concurrently with an expanding but variable and unpredictable contribution from wind turbines.

This presentation has considered the chain of events that could result from the successful development of PHEVs in the context of both Ontario and nuclear power. The widespread adoption of this technology not only leads to new opportunities for nuclear energy but provides a route to an eventual hydrogen economy. To take advantage of this major opening to the future, provision should be made now for industrial complexes located along the Great Lakes such as the Nanticoke region on the north shore of Lake Erie, Hamilton, and even the Bruce Peninsular. Electrical energy would be supplied from nuclear (base load), coal (shoulder load) and wind energy (intermittent) in a complex equipped for carbon dioxide capture from both coal generating facilities and from other industries in the complex (for example, steel production) on a toll basis for sequestering underground. Centralized electrolysis plants producing hydrogen could supply their by-product oxygen to fuel/oxygen combustion facilities generating electricity. This chain of opportunities suggests an eventual energy supply system with two levels of electrolysis facilities – small local facilities and large centralized ones – working in consort with two different classes of coal generating facilities – one based upon combustion to meet shoulder loads and the other based upon the gasification of coal whose hydrogen output would be devoted to meeting peak loads in gas turbines. The hydrogen produced off-peak would be used to power fuel cell-equipped vehicles and for other uses in industry. It is unfortunate that two different types of coal may be needed to achieve maximum efficiency. Given the opportunities for load-levelling because most of the needs of the electric vehicles can be met off-peak, the growth of a widening base load requirement provides substantial opportunities for the expansion of the nuclear option more rapidly than otherwise would be the case.

There is no immediate need for large capital investments to initiate this strategy. The substantial earnings increase to be expected in the utility industry as a result of `filling in the valley' in the daily electrical demand cycle will make the large investments needed later to fund both new reactors and their associated electrolysis plants easier to finance. What is important in the short term is to provide the institutional basis to allow this new direction for the Province with its many opportunities to proceed.

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