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The Nuclear Industry – Time for a Strategic Assessment of Participation in Hydrogen Economy

Vernon J. Kiss

The nuclear industry is primarily focused on electricity production. I believe the time has come to seriously and systematically assess nuclear potential going beyond electricity, in particular focusing on the potential for hydrogen production for use in the transportation industry.

Demand for electricity varies by location, and by seasonal and economic cycles, but overall trends are inescapably strong for continuous demand growth. Furthermore, demand in developing nations is undergoing an even steeper growth rate than in North American and European countries, wherein electric conveniences are already a way of life.

Electricity is of course, not a source of energy. Coal, natural gas, hydro dams and nuclear power plants are the primary sources of energy – electricity, rather, is an energy currency freely traded, transmitted, and distributed on the vast electrical grids that now spread across the continents.

But, although this energy currency - electricity - is produced, traded, transmitted and spent - it is difficult to bank.

Electricity does not store well. Without inventory in the electricity business, the result is daily, weekly and seasonal fluctuations in prices, multiplying in value on hot summer afternoons.

Nuclear power plants represent base load electrical power production only rarely capable of load following, hence their output, while hugely valuable on those hot summer days, is marginal in off-peak periods.

Now let us turn to the energy markets of the world that include far more than electricity. A much larger market includes the supply of energy for transportation. This market is supplied by the oil industry - our cars, trucks, trains and planes run on gasoline, diesel fuel and jet fuel. The hydrocarbon production distribution system is vast. Energy consumed by transportation is roughly three times greater than all electricity generation combined. [1]

Much of the last century led to the development of this transportation energy infrastructure for the supply of primarily liquid, hydrocarbon fuels. These fuels store easily, with high energy density making them ideal for transportation use. The internal combustion engine dominates world energy consumption.

Until now, the interconnections between the hydrocarbon transportation energy system and the electricity generation/power grid systems have been virtually non-existent. Electricity powers immediate fixed needs for energy at locations connected to the grid – while hydrocarbons power mobile engines, with need for stored compact energy requirements.

In the year 2002, there are two distinct and essentially separate energy systems – that of the electrical grid and that which fuels transportation.

This is going to change.

The next decade will continue to illustrate unmistakable milestones in the interaction between the generation of electricity and the transportation energy system. Electricity generation can be redirected to hydrogen production. And the demand for hydrogen is coming.

Technological and socio-political factors will come into play.

First, technological developments.

Already driven by massive investment by automakers, the development of fuel cells has proven the capability for vehicles to operate on pure hydrogen fuel – exhausting nothing but water vapour.

Evidence of this can be seen in announcements by virtually every major auto manufacturer in research, development and now – far more indicative – in goals being set for commercial production and sales. Honda has obtained certification of its fuel cell vehicles in California and Nissan will make a limited number of fuel cell vehicles available next year in California and Tokyo [2].

The largest of the automakers, General Motors, has made news recently with a series of fascinating developments in a new concept of cars – the AUTOnomy [3] and the Hy-wire vehicles [4].

At their heart, they are electric cars, fuelled by pure hydrogen running fuel cells.

As a demonstration of its commitment to commercialisation of these vehicles, this summer in New York State, General Motors unveiled a unique research facility that will further expand its ability to develop fuel cell technology to determine how to go to large-scale production of market-ready products. GM itself has at least 500 people working on fuel cell technology. And recently, the responsible Vice President also declared that GM will be the first company to sell one million fuel cell vehicles [5]. GM is only an example; there are also DaimlerChrysler, Honda, Toyota, Ford, and so on, all of which are expending time, energy and millions of dollars.

Commercial production of fuel cells is pushing ahead (although not quite there). There are many challenges remaining, but the level of commitment should not be underestimated. With any new developing technology, a note of caution should be added to recognise that there are hurdles to be overcome. The cost/performance goals required for commercial use of fuel cells in vehicles still require significant advances. The fuel cell industry recognises that introduction of fuel cells on a widely accepted commercial basis for automobiles is likely to be preceded first by a gradual introduction of fuel cells in stationary backup and quality power applications, and then by bus and truck fleet utilization.

However, the US government FreedomCAR programme [6], the European Integrated Hydrogen Project [7] and the Japan Hydrogen and Fuel Cell Project [8] all represent further world-wide commitments on the part of governments and the auto industry to advance these systems further. In fact, eight of the twelve largest companies in the world are actively involved in these hydrogen/fuel cell development programmes [9].

The second major area of technological development, hand in hand with fuel cells, is in hydrogen storage. Hydrogen can be stored in various ways – cooled and liquefied, under pressure, in metal hydrides, or in chemically bonded forms. Although any one of these may show promise, they also have drawbacks. That being said, certified safe compressed hydrogen gas storage has now clearly been demonstrated, such that automobiles can operate with ranges typical of current gasoline vehicles. For example, the recently announced Honda FCX has a driving range of 220 miles or over 350 kilometres [10]. GM and Quantum Fuel have obtained certification of a 10 000 psi or 700 bar TriShield TM storage tank that could even improve on this range [11].

These and numerous ancillary technology developments point towards commercial introduction of fuel cell/hydrogen vehicles, starting later this decade and accelerating thereafter. Nevertheless, the rate of introduction and penetration into the market is uncertain. But it will happen. These are disruptive technologies that may take time to start but will become major factors in the world's economy.

Furthermore, major social and political factors will accelerate their introduction.

When these cars are available, they will be fun to drive. They run on electric motors. At 0 rpm they have phenomenal torque. These cars will have zip! In fact, the Japanese are already planning auto races to demonstrate their appeal.

On a more sombre note – these cars will kill fewer people with their emissions. Air quality in urban centres is becoming an important public health issue, increasingly recognized by medical practitioners and associations as a significant factor in breathing ailments. In Ontario, Canada, the provincial medical association attributes 1900 premature deaths annually to poor air quality [12]. And this is surrounding Toronto, Canada, not the major urban centres around the world. The population flow world wide to urban centres is growing and massive [13]. This trend to urbanization is compounded in developing nations where expanding urban populations are also increasing vehicle ownership per capita. Clean air will become a volatile political issue.

Another factor promoting hydrogen use is security. Energy security has fundamental implications for developed countries. For example, the US has for decades struggled with its dependence on foreign oil, yet has had difficulty formulating a basis on which to shift away from Middle Eastern suppliers. With 25% of demand and 2% of resources, this problem will not go away easily [13]. Recent events and the stability of regional governments do nothing to reduce this risk. In November last year, the Committee on Sustainable Energy for the United Nations Economic Commission for Europe (UNECE) issued a press release observing an increased sense of vulnerability based on a series of factors including the potential for social unrest and ethnic strife in a number of producing and transit countries [14]. Moderating that demand by shifting even modestly to hydrogen supply of the transportation energy market will remove some pressure on hydrocarbon supply.

Then there are the climate and atmospheric implications – without descending into a debate on the Kyoto Protocol, it is clear that CO_2 emissions world wide are vast and growing, that CO_2 content in the atmosphere is increasing and that world-wide climates are changing [15]. Are these items related? Is there cause and effect? The evidence is extensive. In any event, we now have new evidence of further manmade atmospheric influences. An Asian brown cloud covering 10 million square miles across that continent appears to be the result of vehicular and industrial emissions. The impact of atmospheric emissions will become increasingly apparent in scientific literature and in the minds of those in government.

Back to nuclear power.

Through the introduction of hydrogen-powered fuel cell vehicles, the nuclear energy industry has an opportunity to supply energy to the transportation sector. However, to be clear, this will not be likely to reduce demand for oil. The tremendous growth in energy demand will allow for the expansion of nuclear production of hydrogen alongside continued growth in the oil industry for decades to come. This would still be a fundamental expansion in the application of nuclear energy and will represent a vast market for energy demand that nuclear power is particularly suited to supply.

First, electricity is not a source of energy – it is produced by coal, nuclear, hydro, and natural gas. Similarly, hydrogen is an energy currency that can be produced from any energy source.

Nuclear power can be used to produce hydrogen through electrolysis, or from the thermochemical dissociation of hydrogen from water. The WNA has reviewed this information in its briefing papers.

Second, nuclear power is a baseload power source, and at night when nuclear plants still produce energy – which no one is particularly interested in paying much for in the form of electricity – it can produce hydrogen.

Third, hydrogen – unlike electricity – can be stored, and so the tremendous value of nuclear power can be translated into energy for the transportation energy system, a vast market into which nuclear power can now penetrate. Professor Paul Kruger of Stanford University has estimated that requirements for meeting this demand, but avoiding carbon emissions, will require hundreds of nuclear plants in the coming decades, unless one believes that renewable energy systems can grow at staggering rates [16].

A simple illustration shows the economics and the potential of linking nuclear power to hydrogen, and hydrogen to transportation. A tankful of gasoline, 12.5 US gallons or 47 litres, at US$1.50 per gallon will cost US$18.75. At 20 miles per gallon or 11.7 l/100 km, that will take you a distance of 250 miles or 400 km.

What the automakers say is that about 3 kg of hydrogen will get you the same distance. To produce this requires 150 kWh – then at 6 cents/kWh it will cost US$9. With an additional 33% for fuelling services and equipment, the cost still comes in at only US$12. Of course, changes in tax structures may have dramatic implications. Moreover, fluctuations and regional differences in gasoline prices will skew any analysis. But here is another key point, which should not be underestimated: although gas prices exhibit high variability and the world's economy shudders at every rise in the price of crude oil, the cost of hydrogen production from nuclear will instead exhibit a moderated price index and highly predictable rates. One need only examine overall publicly published costs of US nuclear power production to see the strides made in controlling and reducing input costs for nuclear power production [17]. This high degree of certainty in energy costs can be translated into far more predictable and reliable energy costs in the transportation sector, a factor that should be addressed with policy makers.

Accordingly, on the basis of current costs, distribution systems, known technology and existing taxation, but with the introduction of commercial fuel cell vehicles, nuclear power-produced hydrogen can compete with gasoline on a per kilometre or per mile basis. I mention taxation as it is an obviously important issue, but it is beyond the scope of this discussion.

This paper only touches upon the many issues relating to the implications of nuclear power production of hydrogen for fuel cell driven transportation. But I note that the fuel cell/hydrogen industry is growing in stature and maturity. The World Hydrogen Conference this past June in Montreal demonstrated an ever-increasing commitment to its commercial success on a world-wide basis [18]. But focus on production and a strong vocal nuclear industry presence were lacking. Various US, European and Japanese studies on energy supply have tended so far to gloss over or completely overlook the tremendous potential for nuclear power to address clean air, emissions reductions, cost volatility and energy security issues in the coming hydrogen industry.

In conclusion:

The WNA and the NEI in the US should ensure that nuclear power is considered in studies undertaken in connection with the supply of hydrogen for use in transportation.

A framework for assessment should be created to review the impact on costs, emission reductions, energy security and price volatility if nuclear power were to become a major source of energy to supply hydrogen to the transportation market.

Support should be given to research, to develop and improve efficient means of hydrogen production from nuclear power.

The nuclear industry is capable of executing visionary long-terms plans. This industry should aspire to participate in the hydrogen economy as a key strategic objective, and, although the final commercialisation of fuel cells is still years in the future, the time for modest steps in forward planning is now.

NOTES

1. A commercially produced and generally well regarded survey of international energy information is found in the British Petroleum (BP) Statistical Review of World Energy produced annually. It is located at www.bp.com/centres/energy2002.

2. All major automotive manufacturers have actively updated websites on which their numerous press releases tout their achievements in low emission vehicles. As these developments are now being updated often (several times a year), consulting each for the most recent information is useful. However, it should be noted that these corporations are fuelled by intense rivalry and discerning hype from real progress is not always possible without further research.

3. The AUTOnomy vehicle was announced by General Motors in January 2002 as the first concept vehicle designed from the ground up around a fuel cell with all steering, braking, and other vehicle systems controlled electronically. The result was a new vehicle architecture allowing a great variety of all-wheel drive vehicles from very few common chassis. See: www.gm.com/company/gmability/environment/road_to_future/adv_tech_vehicles/future_fuel_cells/index.html.

4. In an announcement on 14 August 2002, General Motors stated:

   Driving closer to reinventing the automobile, General Motors Corp. today revealed a look at Hy-wire, the world's first drivable vehicle that combines a hydrogen fuel cell with by-wire technology.

   The GM Hy-wire, appropriately named for its technology, incorporates the features first envisioned in the AUTOnomy concept vehicle at the 2002 North American International Auto Show in Detroit and the Geneva Motor Show. Hy-wire will be introduced to the public at the Paris Motor Show Sept. 26. . . .

   'The fact that we developed Hy-wire as a drivable concept vehicle in just eight months (from its introduction in Detroit) shows our commitment to this technology and the speed at which we are progressing,' said Rick Wagoner, GM's president and CEO.

   'With AUTOnomy, GM shared a vision. Hy-wire accelerates our progress with a functional proof of concept which strengthens our confidence in our ability to gain marketplace acceptance of production fuel cell vehicles.'

Larry Burns, GM's vice president of research and development and planning, said, 'We are driving to have compelling and affordable fuel cell vehicles on the road by the end of the decade. With Hy-wire, we have taken the technology as it exists today and packaged it into an innovative drivable vehicle comparable in size and weight to today's luxury automobiles.'

5. 29 July, 2002.

6. On 9 January, 2002, US Secretary of Energy, Spencer Abraham announced: 'a new public-private partnership between my department and the nation's automobile manufacturers to promote the development of hydrogen as a primary fuel for cars and trucks, as part of our effort to reduce American dependence on foreign oil, . . .'

   'Under this new program, which we call FreedomCAR, the government and the private sector will fund research into advanced, efficient fuel cell technology, which uses hydrogen to power automobiles without creating any pollution. The long-term results of this cooperative effort will be cars and trucks that are more efficient, cheaper to operate, pollution-free and competitive in the showroom.'

   See: www.cartech.doe.gov.

7. See: www.eihp.org.

   Phase I objectives are set out below and Phase II is now being undertaken.

   Implementation of hydrogen vehicle and infrastructure technology can only succeed if the co-ordination of European R&D activities are intensified and technical progress is not hindered by differing regulations and licensing procedures within the EU member states.

   This project, which aimed at creating the basis for harmonisation of necessary legislation in Europe, was undertaken in close co-operation with licensing authorities in several EU member states (Belgium, France, Germany, Spain, Sweden).

   The main objectives of this project were to: identify deficiencies impeding the harmonisation of guidelines, regulations etc., co-ordinate harmonisation in the approaches to standardisation; prepare a well-defined basis for discussion with relevant authorities; integrate the practical experience with hydrogen vehicles in the draft regulations; integrate existing ECE frameworks; and develop concepts for standardised vehicle components and infrastructure.

   The particular objectives of the EIHP were:
   To create a pan-European database of existing regulations and codes of practice applicable to the use of hydrogen in vehicles.
   To contact other pertinent authorities outside Europe (Japan, USA).
   To identify weak spots in today's technology.
   To define the areas requiring regulation.
   To analyse, identify and propose safety concepts.

To integrate ECE guidelines and create a basis of ECE regulation of hydrogen vehicles and the necessary infrastructure (replacing national legislation/ regulations).

As a result, proposals for further investigations and improved safety concepts were compiled, together with concepts for standardised vehicle components, infrastructure components and draft harmonised regulations.

8. The Japan Electric Vehicle Association (JEVA) recently announced that the government of Japan will soon launch a three-year joint test of hydrogen and fuel cell vehicle (FCV) technology on the country's roads. The test project will include Japanese automakers Toyota Motor Corporation, Honda Motor Company and Nissan Motor Company, US auto manufacturer General Motors (GM) Corporation and German-US carmaker DaimlerChrysler AG.

   JEVA said the Japan Hydrogen and Fuel Cell (JHFC) demonstration project will be sponsored by Japan's Ministry of Economy, Trade and Industry and will examine the 'effectiveness, environmental friendliness and safety of [FCVs].' Additionally, the project will promote public awareness about fuel cells and the use of hydrogen 'as a safe and clean fuel.'

9. ExxonMobil, General Motors, Ford Motor, DailmerChrysler, Royal Dutch/Shell, BP, Mitsubishi, Toyota Motor (based on revenues 2000 *Fortune).*

10. In July 2002, The American Honda Motor Company, Inc. announced that the Honda FCX fuel cell vehicle (FCV) has been certified by the Environmental Protection Agency (EPA) as a Tier-2 Bin 1 national low emission vehicle (NLEV) and by the California Air Resources Board (CARB) as a zero emission vehicle (ZEV). Honda said the FCX will also meet applicable US safety and occupant protection standards.

    Honda said the FCX achieves 15% more maximum drive motor torque than the company's previous FCV models and also provides improvements in mid- to high-range power output characteristics and acceleration. Additionally, the FCX has an increased driving range of 220 miles, about 25 miles more than the previous model.

11. In August, 2002, General Motors and Quantum Fuel Systems Technologies Worldwide, Inc. (Quantum FSTW) announced that German safety institute Technical Inspection Association (TUV) has certified Quantum FSTW's 10 000-pounds per square inch (psi) hydrogen storage system. Previously, only hydrogen storage tanks with a maximum capacity of 5000 psi had met the requirements for TUV certification.

    The companies said the 10 000-psi hydrogen storage tank features Quantum FSTW's TriShield design, which includes a one-piece permeation resistant seamless liner, a high-performance carbon composite over-wrap and a proprietary impact-resistant outer shell. The system has also been validated according to European Integrated Hydrogen Project standards.
    See: www.qtww.com.

12. See: www.oma.org/phealth/smogmain.htm.

13. The world has experienced unprecedented urban growth in recent decades. In 2000, about 47% of the world's population lived in urban areas, about 2.8 billion. There are 411 cities over 1 million. More developed nations are about 76% urban, while 40% of residents of less developed countries live in urban areas. However, urbanization is occurring rapidly in many less developed countries. It is expected that 60% of the world population will be urban by 2030, and that most urban growth will occur in less developed countries. (From the United Nations, *World Urbanization Prospects* revised annually).

14. UNECE, 'Concern about Energy is Growing', Geneva, 22 November, 2001, www.unece.org.

15. The Intergovernmental Panel on Climate Change reports are comprehensive summaries currently available on such evidence. See: www.ipcc.ch.

16. Electric Power Requirement for Large-Scale Production of Hydrogen Fuel for the World Vehicle Fleet, Paul Kruger, Stanford University, in *Building the Hydrogen Economy* 11th Canadian Hydrogen Conference – Canadian Hydrogen Association.

17. Production costs have declined from 2.98 cents per kilowatt-hour to 1.74 cents from 1987 to 2000 as seen in the data accumulated by the Nuclear Energy Institute. See: www.nei.org under Nuclear Data for the most recent information available.

18. The 14th World Hydrogen Energy Conference was held 9-13 June, 2002 in Montreal Canada, featuring *The Hydrogen Planet*. Full details can be obtained at www.hydrogen2002.com.