USAWC STRATEGY RESEARCH PROJECT

CONVERSION TO A HYDROGEN FUEL TRANSPORTATION INDUSTRY, INCREMENTAL ROUTE OR DIRECT ROUTE?

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ABSTRACT

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This research project reviews current transportation industry policies of the United States and uses the ends-ways-means strategic model to examine the course of action government and industry need to take to reach policy objectives. It begins by reviewing the key objectives of the transportation industry in energy policy documents. It explores the economic (domestic and foreign) and geo-political implications of converting to a hydrogen fuel transportation industry and of failing to convert. Finally, it identifies two approaches to implement the conversion, the incremental conversion approach and the direct conversion approach. It investigates the level of effort required from government and industry for both approaches, the environmental impact of both approaches, and the economically feasible time line available.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CONVERSION TO A HYDROGEN FUEL TRANSPORTATION INDUSTRY, INCREMENTAL ROUTE OR DIRECT ROUTE?

Despite President George W. Bush's best efforts in compiling a blueprint for a comprehensive energy policy, Congress has failed to pass legislation that supports that policy. [1] The fact that Bush has enjoyed a majority in the House of Representatives and a split Senate should provide insight into just how divisive the President's energy policy has become. The following quote is taken from the Energy Department Assistant Secretary for Efficiency and Renewable Energy, David Garman's, question and answer website.

> Respondent: "The United States does not have a comprehensive energy policy, because most of the energy is monopolized by the oil industry.
>
> 1. When will the United States have an energy policy that is conducive to utilizing renewable and alternative energies?
>
> 2. Instead of subsidizing the oil industry, when will the alternative technologies for energy be adequately supported?
>
> Instead of more vehicles, when will the government espouse more mass transportation?"
>
> David Garman: "We hope Congress will soon pass a comprehensive energy bill that contains some of the elements the President has asked for, including: 1) Production Tax Credits for renewable energy such as wind and biomass; 2) tax credits for hybrid vehicle purchases; 3) a residential solar energy tax credit; 4) progressive regulatory treatment for combined heat and power; and many of the other features in the President's plan.
>
> Also, the President's budget for renewable energy is up 4.8% this year over last year's appropriation."[2]

Some would argue that the United States has had an effective energy policy for the past 30 years since the Arab oil embargo of 1973. This policy has concentrated on the supply side by effectively keeping the global price of oil at or near competitive market levels.[3] At the same time regulatory policies on the demand side have caused a significantly increased conservation effort from private industry. For example, modern day refrigerators use one third the electrical energy they did 30 years ago. Such a policy has led to popular complaints regarding higher oil prices, but still nothing happens to make us less dependent on imported oil, especially in the transportation sector.

Thus, the United States has no comprehensive energy strategy to guide it through the transitions of technology required to end its dependence on imported oil. "Transportation plays a key role in a growing U.S. economy, comprising 16 percent of GDP in 1998, 10.5 percent of total employment, and 27 percent of total U.S. energy consumption."[4] Fossil fuels provide 80 to 90 percent of that energy.[5] Just over half of that oil and natural gas is imported. Bush's energy policy considers transportation, especially vehicles like cars, to be intricately interwoven into the overall strategy. "Most of the future growth in energy is expected to take place in transportation, where motorization continues to rise and where petroleum is the dominate fuel, accounting for 95 percent of the total."[6] I suggest that the lack of a comprehensive transportation policy with the required fuel supply logistical tail is adding to the "Energy Crisis" that the President declares in his Energy Policy.[7]

Decreasing fossil fuel consumption with non-fossil fuel consuming automobiles would serve to decrease oil demand significantly, which in turn would free resources to other key transportation sectors like air travel.[8] Transportation requirements eat up a significant part of the nation's energy bill. Developing a clean, renewable form of energy to supply our transportation needs also has side benefits. We would need less imported oil, produce fewer greenhouse gas emissions and we would not have to worry about spending resources on the Carter Doctrine of keeping the sea lines of communications open in the oil-rich regions of the world. Indeed, in the future, the United States may be faced with fighting wars in oil-rich nations to meet our ever expanding appetites for energy.

FOCUS OF OUR CURRENT ENERGY POLICY

Of the 98 recommendations of the National Energy Policy, prepared by the National Energy Policy Development Group (NEPD Group), signed by all the Administration cabinet members, among other senior government officials, 48 deal with fossil fuel exploration and development. There are 40 recommendations that deal with administrative, legislative or conservation issues. Only ten recommendations deal with renewable energy sources or alternatives.[9] Bush deleted one of the Clinton/Gore transportation goals of developing a gasoline powered internal combustion engine capable of getting 75 miles per gallon.[10] Instead, he is concentrating on developing an automobile that runs on Hydrogen Fuel Cell technology. Still, Corporate Car Automobile Fuel Efficiency (CAFÉ) goals and the Arctic Natural Wildlife Refuge remain in the policy initiative, which continue to be sources of great disagreement and illustrate, with just a couple of examples, of how difficult it has been and will continue to be to come to consensus on an omnibus energy bill.

Even though one of the policy's primary goals is to reduce our dependence on imported oil, the policy itself spends more time on developing the markets that will continue our dependence on oil. Although estimates vary widely – from 20 years to up to 50 years and beyond - on how much readily recoverable oil is left, eventually we are going to run out. The reason for the disparity in estimates is two-fold - industry tends to understate the reserves' magnitude so as not to betray public confidence and oil exporting governments tend to overstate reserves for quota reasons. When we reach the peak of production, as some suggest we already have, we will plunge into a continual oil crisis. After our peak production, market oil prices will only rise.[11]

COURSES OF ACTION

STATUS QUO

Even though President Bush declared an energy crisis in 2001, most of our energy research and development money is still earmarked for exploiting fossil fuel.[12] Continued reliance on oil and natural gas will mean that we suffer the whims of exporting energy producers, continued elevation of greenhouse gasses that are thought by most scientists now to be the leading cause of global warming,[13] and despite the disagreement on exactly how much oil is left, we will eventually run out. It is non-renewable.

Effects on National Economic Security

Adhering to the status quo would have a continued negative impact on the United States' economy: In his Foreign Economic Policy for the next President, C. Fred Bergsten writes,

> Energy is another area in which the United States is vulnerable, in both economic and foreign policy terms. The lack of an effective energy policy-highlighted once again by the recent failure of Congress to pass adequate legislation after three years of effort-keeps U.S. foreign policy beholden to a few key producers and will probably force the United States to continue to launch periodic military interventions to satisfy its tremendous appetite for energy.

Bergsten goes on to say that the Organization of Petroleum Exporting Countries (OPEC) have manipulated world oil prices by holding them 50 to 75 percent above market levels, which has effectively squeezed about one percent annual growth from the United States' economy since OPEC was established.[14]

With the exception of the United States Navy's widespread use of nuclear power to propel its aircraft carriers, surface ships and submarines, our military plans to continue to rely primarily on fossil fuels to supply its transportation needs. The United States Army plans to employ advanced diesel or gas turbines for its next generation of surface mobility vehicles.[15]

Effects on Foreign Economies

The continued pursuit of the status quo would also have a profound impact on not only the United States' economy, but also those of foreign economies, both of oil importing and oil rich countries.

"Higher world oil prices also threaten the economic health of many small nations. This in turn, affects their ability to produce exported goods and services and can seriously reduce their ability to buy imported American goods"[16]

Countries that cannot afford oil when prices rise may slip into recession. This could have a dramatically negative impact on their people or their nation as a whole, and could, in turn, adversely affect regional stability. In such cases, the United States might feel compelled to deploy troops to restore/maintain stability.

Conversely, oil-rich countries rely on rising oil prices to support their economies as they have not taken appropriate steps to diversify. Robert Mabro eloquently states,

> Countries that depend heavily on oil revenues face the daunting challenge of transforming their economies to enable them to grow in an era of reduced oil income. The time available for this transformation is of the order of 20 or 30 years, but this is not as long as may appear at first sight. In the early 1970s many among us thought that the newly accrued oil wealth should enable the Gulf countries to build the foundations of a non-oil economy capable of sustaining long-term economic growth. Thirty years have elapsed and these foundations are not yet there.[17]

Saudi Arabia, for example, relies heavily on oil revenues to support its economy and government. The United States has espoused a particular interest in the stability of the Saudi Arabian government. The Saudi economy suffers from a high rate of unemployment. If oil prices decline, the unemployment problem is exacerbated. The problem becomes even worse as disaffected youth begin to feel disenfranchised from their government. Many of these have already affiliated themselves with popular, radical Islamist movements, some of which advocate the overthrow of their government. Again, the United States may feel compelled to deploy troops to maintain regional stability. Such effects on foreign governments have a complementary impact on the security of the United States.

Pursuing the status quo will significantly affect other geo-political situations of the world.

> Western nations consumed the vast majority of energy during the last century, but within a few decades, the energy demands of the developing countries of Asia, Latin America, and Africa are expected to meet and surpass those of the West. How countries like China and India meet their energy needs will have an enormous impact on the world's energy trade, and on the environment.[18]

With the enormous growth rate of the Chinese and Indian economies, they may seek to assure access to world's oil and gas supplies by building large navies and military forces.

The time is quickly approaching to avert an untenable crisis by investing more in renewable energy research and development, in the infrastructures required to support them and the proper coordination between government and industrial sectors. Whereas Federal research and development outlays for total fossil fuels between 2001 and 2003 are $364.177, $431.366, and $415.902 million respectively, total outlays for renewable R&D for those years declined to $258.479, $251.404 and $242.659 million[19]. Continued reliance on fossil fuels and no immense government coordination threatens to leave us like the oil producing countries 30 years ago.

It is clear that the United States is not focusing enough resources on the energy crisis. The current level of effort is not sufficient.

TRANSITION TO A HYDROGEN ECONOMY

Figure 1 shows how, in a relatively short span of time, the petrochemical industry has come to dominate our society.

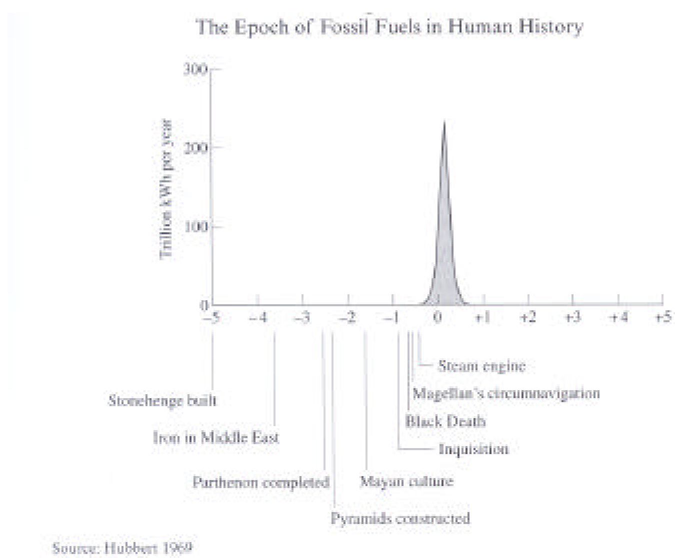

FIGURE 1 EPOCH OF FOSSIL FUELS IN HUMAN HISTORY COURTESY: HUBBERT FOUNDATION[20]

It also shows that just as soon, we will be faced with two choices. We can either convert to another energy carrier that provides us with the same energy delivery capacity as petroleum and natural gas and that does not harm our environment, or we can revert back to earlier, agrarian days and have to accept the reduced standard of living that that prospect entails. The transition to the past, I venture to say, will be considerably more painful than pressing on to a future energy carrier.

What will that carrier be? There are few options. Nuclear production is a candidate, but it comes with burdening regulatory constraints, the unpopular issue of how to manage spent nuclear fuel rods, and a public acceptance problem. Additionally, an immense level of effort will be needed to replace the electrical production capability of coal, oil and natural gas with nuclear power, and its application to the current transportation system would be negligible. Conceivably, electricity generated from nuclear powered electric generators could supply the power to charge batteries to run electrical cars, but with the current state of battery technology, they would be short range vehicles. Hydro-electric energy is nearing its maximum potential. Fusion technology, the “New Nuclear” power, is not expected before the middle of this century, and hydrogen will be required for its fuel stock. Renewable technologies such as wind, solar and biomass are not yet developed to the capacity necessary to satisfy the world’s inhabitants’ tremendous appetites for energy.

Methanol is a candidate. It can easily be produced from biomass and fossil fuels. The infrastructure is already in place to support a methanol economy and it is a very efficient fuel stock. It is easily and safely produced, stored, transported and distributed to the end user. [21] But it is, after all, a hydrocarbon. Additional cost and management would have to be expended to manage the increased carbon dioxide levels of the atmosphere associated with hydrocarbons. Methanol is also classified as a toxin and has an invisible flame when burned, so it carries with it health and safety issues as well as liability issues.[22] It goes much the same for natural gas and methane.

One factor that will significantly affect energy policy is concern for the environment. It is difficult to determine exactly what limit of greenhouse gas content the Earth’s atmosphere can sustain before devastating environmental effects occur. However, it is generally agreed that a “sustainable” level must remain below 550 parts per million. That means that the world must achieve a reduction in greenhouse gas emissions of 50 percent by 2050. Unfortunately, world energy consumption is on the rise and unless robust and costly carbon sequestration procedures are implemented, reliance on hydrocarbons will not keep the greenhouse gas concentration below 550 parts per million.[23]

Hydrogen cannot by itself solve all the problems of our petroleum driven economy. By converting the motors of our transportation sector to hydrogen fuel cells, in conjunction with using hydrogen fuel cells to provide cellular energy sites to our homes and offices, we can, however, cut the amount of carbon dioxide currently being released into the atmosphere and thereby ameliorate many of the adverse effects on our environment and economy. Additionally, these compact cellular fuel cells can enhance the inhabitants of sparsely populated, energy poor regions of the world[24]

> "Many observers predict that, during the 21st century, the world's energy culture will undergo a transformation…. Energy sources like solar and wind are emerging as viable alternatives, and nuclear power, once thought to be on its way out, is once again being heralded as an energy solution. The most excitement – and the least controversy – surrounds hydrogen, which Jules Verne imagined over a century ago would be the "coal of the future."[25]

Hydrogen promises to provide a clean, efficient form of transportation. The diatomic fuel source, H_2 gas, may be derived from a great number of sources – not only from naturally occurring hydrocarbons, which would continue to contribute to the status quo, but from much more promising economical and environmentally sound sources as well. Renewable energy sources are being developed to obtain H_2 gas, although at a rate insufficient to spur required changes in the energy and transportation industries.

There are other ways to derive H_2 such as biomass, wind driven turbines, photoelectric and photo thermal techniques from solar energy, geothermal energy, and the energy from sea currents and sea wave action. Nuclear energy, despite its own problems, has near term potential for generating the power required to produce free hydrogen molecules.

Electricity generated from these sources can be trickled through water electrolyzing it to liberate hydrogen from oxygen. Free Hydrogen gas can be collected and compressed for use in hydrogen fuel cell applications and direct use applications. Hydrogen fuel cells reverse the hydrolysis process by taking oxygen from the air to produce water, heat and an electrical current. The electrical current is sufficient to drive automobiles, provide energy to heat and cool homes and to provide a constant and stable source of energy to power personal computers.

Of particular interest to the automobile industry is the proton exchange membrane fuel cell (PEMFC). They are well-suited to providing a reliable power plant for automobiles. See the illustrations at the end of this report for details on how PEMFCs work.

Conversion to a hydrogen economy will clearly require advancements in existing technologies for producing, storing, transporting and distributing hydrogen. Hydrogen is the most abundant element in the observed universe, but it doesn't occur on Earth in its elemental form. It is chemically bound up in water and all living tissue. Water, the most abundant compound on Earth, is two atoms of hydrogen chemically bound to one atom of oxygen. Energy is required to liberate free hydrogen from its naturally occurring states. The amount of energy required depends upon the process used. It is generally agreed that economically feasible processes to generate the amount of hydrogen required to transition to a hydrogen transportation industry will be achieved in the next decade. Once liberated, hydrogen is an efficient energy carrier.

Challenges exist with storing and distributing hydrogen. It is not very useful at ambient pressures. It must be pressurized or liquefied in order to be useful in hydrogen fuel cells, internal combustion engines or gas turbines. Liquefaction supplies a more useful and economically transportable form of hydrogen than pressurization. It is also more expensive, with as much as 30 percent of its fuel value used up in the liquefaction process. [26] Pressurized hydrogen can be transported either by truck or through pipelines. Because of the low density of hydrogen, the energy expended transporting it by truck exceeds the energy value of the hydrogen cargo after about 500 kilometers. Some hydrogen pipelines exist for chemical purposes. Natural gas pipelines can be modified to transport hydrogen at great expense. Pipelining hydrogen is energy intensive, consuming 4.6 times more energy to transport than for natural gas.[27] Consequently, pressurized hydrogen consumption is currently limited to the locality of its production. In the near future, H_2 production sites will probably located at regional bases like local utilities. In the longer term, many envision H_2 production plants located at individual residences.

New technologies are emerging that promise to remedy some of these technological problems with transporting hydrogen, which might soon greatly enhance the stored energy density of hydrogen. Potential solutions include high pressure tanks in light weight materials, metal hydrides and carbon structures (nanotubes and fullerenes). High pressure tanks can store hydrogen in densities four or five times that of the pressurized containers commonly used in industry today. Installation of burst fuses and interruption valves mitigates the burst risk of these devices. Metal hydrides show promise in increasing the energy density of hydrogen fuel stock although they are bulky and expensive and function at a wide range of temperatures, which presents problems in selecting materials to contain them. Perhaps the most promising breakthrough is in the field of carbon structures. Certain structures have been found that can store hydrogen in concentrations up to 60 times that of hydrogen at room pressures. [28]

Transitioning to a hydrogen economy is full of promise. Phillip Tseng, John lee and Paul Friley of the Office of Energy Efficiency and Renewable Energy for the U.S. Department of

Energy conducted a study on the opportunities and challenges of a hydrogen economy using a complex modeling method known as the U.S. MARKAL model. Their purpose was to "dynamically simulate the effects of a hydrogen economy on the energy sector, capture the interactions between hydrogen- and petroleum-based fuels, and identify the social costs and benefits of the transformation to a hydrogen economy."[29] Using conservative assumptions, not the least of which is a modest 3% annual rise in the price of oil, they limited their analysis to a hydrogen economy that might stem from the most likely sources of hydrogen production – coal, natural gas, biomass and electrolysis. They report,

> The existing infrastructure for petroleum-based fuel and vehicles clearly has an advantage over that for hydrogen and fuel cell vehicles. This lock-in effect for conventional technologies effectively locks out new ones. While building the required infrastructure is indeed a significant barrier to the hydrogen economy, the costs of producing hydrogen and fuel cell technologies are as important. A frugal consumer will not buy a hydrogen fuel cell vehicle if both it, and the fuel, cost more than conventional technologies.[30]

The analytical approach developed by Tseng et al established a reference case based on the current petroleum based economy, with no introductions of incentives to convert to a hydrogen economy. They then developed a hydrogen economy case, where they identified and included in their analysis specific research and development programs that would facilitate the implementation of hydrogen technologies. Finally, they contrasted the two scenarios through the year 2050. The U.S. MARKAL model showed that technology efficiencies in hydrogen production and fuel cell vehicle improved over time, making them more economically competitive. The nature of the petroleum-based economy becomes more uncertain as it is phased out in the transportation industry.

If natural gas becomes the predominant form of electricity and hydrogen production (a scenario where existing infrastructure can easily be converted from one to the other), the cost of natural gas will rise with the corresponding demand. The rise in the price of natural gas could become the impetus to alternative technologies for producing hydrogen. Conversely, the cost of oil, especially light crude, from which gasoline is distilled, will fall along with the fall in demand. The fall in demand for gasoline should compel the petrochemical industry to develop newer technologies for the production of petroleum distillate products that are currently more readily rendered from heavy crude, shale oils and coal. Additionally, as demand for gasoline sags, supply of other distilled petrochemical products will drop commensurately. Both occurrences will provide strong upward pressures on the prices of these other petrochemical products.

If, on the other hand, alternative methods of producing hydrogen such as biomass, nuclear, solar or wind become economically viable, overall oil prices would drop to remain competitive, which will effectively inhibit any lock out technologies and infrastructures.[31] However, this would have the unintentional effect of prolonging our dependence on petroleum.

The U.S. MARKAL study concedes that the supply of crude oil could be more restricted and fetch higher prices than are assumed for the analysis. In that case, the costs of technologies of transitioning to a hydrogen economy could be higher and still be economically viable.

The results of the analysis concluded that,

> The transition from a petroleum-based energy system to a hydrogen economy will reduce demand for petroleum, lower oil prices, and reduce crude oil throughputs into petroleum refineries. Energy security will improve as sources become more diversified. Emissions of carbon dioxide also are projected to decline because of drastic improvements in fuel efficiency in the transport sector. A very important finding is that the value of gasoline will decline as the demand for it decreases. However, the value of other petroleum products will increase in the energy system because their supply will fall with lower refinery throughput.[32]

The study finds economic and technological stimulation and environmental improvements in transitioning to a hydrogen economy both in a world where oil and gas are abundant and in a world where they are not.

Challenges of transitioning to the hydrogen economy involve improving all phases of hydrogen production - storage, transportation and distribution in conjunction with revolutionary technological breakthroughs in hydrogen fuel cell technologies and vehicle drive trains. Introduction of these capabilities must be implemented near simultaneously to prevent the chicken and egg problem, an economy killer. The cost of hydrogen fuel must be equivalent or lower than gasoline prices.

Hydrogen Safety

Certainly, without public support of the technology, the hydrogen economy could never become viable. Many question the safety of the technology. After nearly 80 years, hydrogen disasters are associated with the 1937 *Hindenburg* explosion at Lakehurst, NJ. Addison Bain, a respected NASA scientist painstakingly analyzed a fragment of air ship skin recovered from the explosion. He found that it was made of cotton cloth covered by a doping process that used aluminized cellulose acetate butyrate and iron oxide, essentially the same elements that the Space Shuttle uses for its solid rocket fuel. Photographs of a Navy dirigible that caught fire during a rainstorm near a Naval Air Station in Georgia in July of 1956 looked surprisingly similar to the *Hindenburg* disaster. The Navy dirigible was filled with non-flammable Helium. Bain concluded “don’t paint your air ship with rocket fuel.”[33]

On March 27, 1977, two Boeing 747s collided while one of the planes was just taking off at the Tenerife airport in the Canary Islands. There were 644 souls on board the two planes, of whom 583 lost their lives. G. Daniel Brewer, of Lockheed's hydrogen program, argues that the loss of life would have been greatly reduced had the two planes had been fueled with hydrogen. He estimates that in the accident only about 25 or 30 people would have been killed upon impact with the ground, but the remainder would have burned to death in the fire ball that lasted for over ten hours. If the aircraft had been fueled with hydrogen, Brewer reckons that because of its burn characteristics, the liquid would have evaporated quickly and the ensuing fire would have been much less severe so that many more lives could have been rescued.

How Do We Transition?

Most would agree that the transition to a hydrogen economy, especially for the transportation industry is in the world's best interests. The question remains, how do we get there from here? Should we rely on an evolutionary transition allowing market forces to take their course? In this case, transitioning to a hydrogen economy will require economic incentives that encourage implementing new technologies and then identifying niche markets where segments of the economy can be introduced without the incentives.[34]

On the other hand, the United States could transition to a hydrogen economy in a revolutionary manner, with a strong lead by government. "If we set our minds to it, we could accomplish a hydrogen economy by 2010"[35], but it will take the level of effort of an Apollo project.[36]

Of course there is some combination of these two methods involving a partnership between government and industry. Japan is pursuing this route. The Japanese government will invest $4 billion by 2010 to transition to a hydrogen economy. This effort is considered to be the most comprehensive program in existence.[37] Japan has a very close partnership-type working relationship between their government and their industry. This partnership is not without problems, however, as it opens up opportunities for corruption.

The Iceland Project is another example of partnering government and industry. It is a consortium of investors from the European Union, industry and the Icelandic government. The Iceland Project plans to replace the diesel engines of Iceland's entire fishing boat fleet with hydrogen fuel cells. Additionally, they will replace a large number of public transportation buses driven by internal combustion engines with hydrogen fuel cell driven buses. The energy required to electrolyze water to produce hydrogen will come from Iceland's' vast, naturally occurring geo-thermal stores.

It is dawning on the United States automakers that they need to improve the working relationship with government to implement a viable hydrogen economy, but they are uncertain how to proceed.[38] One thing is clear, "a broad based, cooperative coalition for change is the missing, indispensable ingredient in transforming a strategic energy vision into reality."[39]

Incremental Transition to a Hydrogen Transportation Economy

One of the main obstacles to converting to a hydrogen economy is the perception that it will cost hundreds of billions of dollars to replace the existing infrastructure of the gasoline centered transportation sector. Systems would have to be developed to produce, transport, store and deliver hydrogen fuel. Conventional wisdom suggests that an incremental approach makes the most sense. One could use the gas pumps of existing filling stations to provide a form of hydrogen presumably liberated from hydrocarbons, similar to the diesel pumps available today. The hydrogen could be liberated from petroleum products on site by an installed converter, or the automobile industry could manufacture a "transition" hydrogen fuel cell car that liberates hydrogen from gasoline or diesel fuel as the automobile operates. This process would be accomplished by an onboard reformer that strips the hydrogen from the hydrocarbon being used. Such a process emits about the same amount of greenhouse gases as burning the hydrocarbon in an internal combustion engine. Internal combustion engines that operate on pure hydrogen or a blended hydrogen fuel could also be part of the incremental strategy.[40]

The choice of fuel that society chooses may be driven by which technology society selects. The technology selection will be influenced by a number of variables, such as government/industry interactions, research and development, market pressures and personal preferences. If we choose the incremental approach that uses existing infrastructure to deliver gasoline to fuel cell vehicles equipped with an onboard reformer, we may effectively lock out technologies aimed at providing direct use hydrogen from renewable resources, depriving our society of the benefits that they bring.

In the mean time, it is imperative that we continue to develop hydrogen fuel cell technology automobiles along with the required infrastructure in a spirit of cooperative agreement between government and industry with industry taking the lead.

At the same time, we must continue research and development for direct use of hydrogen fuel in airplanes and military equipment and explore nanotechnologies to supply us with personal, home and office energy requirements.[41] Such an approach will reduce our dependence on imported oil and spread the remaining oil out further in time.

A smart energy policy that offers a combination of tax incentives to buy new technology vehicles and regulations and subsidies for hydrogen fuel production and distribution could go far in assisting the transition to the hydrogen driven transportation industry. An incremental transition with limited involvement of the United States Government could be possible.

Direct Transition to a Hydrogen Transportation Economy

Clearly, the quickest and most deliberate route to a hydrogen transportation industry would be a direct transition. If large scale hydrogen production is established from renewable sources, Paul Kruger of Stanford University

> projects that hydrogen powered fuel cell vehicles could almost completely replace the U.S. car fleet by 2050. By one estimate, the fuel needs of the entire U.S. fleet of 200 million could be met by dedicating a small amount of land in the southeast to solar hydrogen. Fourteen percent of the U.S. wind resource that could be developed is also estimated as sufficient to supply hydrogen to the entire national fleet.[42]

The transition costs would be high, but would they be higher than the costs of the incremental approach? Recently, a number of scientists have challenged the notion of an incremental strategy and assert that such a bridge technology would prolong our dependence on importing oil and would deprive our society of trillions of dollars worth of benefits.[43]

In a 1999 paper from the Hydrogen Technical Advisory Panel (HTAP), a group of scientists charged with providing hydrogen policy advice to the U. S. government, argues that both industry and government are "providing substantially greater support for onboard fuel processing – despite the significantly greater long-term societal benefits of direct hydrogen."[44]

The most significant challenge to directly transitioning to a hydrogen economy is the absence of a sufficient level of effort from government and industry. Consequently, the lack of a robust energy policy will likely lead us to the incremental conversion. United States' industry is oriented too much on the short to medium range profit margins to invest the level of effort required to pursue the more difficult direct route to the hydrogen economy.[45] "GM executive, Larry Burns, asserted that, in the 'race to affordability' for fuel cell vehicles, significant investment from federal and state governments will be a key factor in developing the necessary hydrogen infrastructure."[46]

Affecting a direct transition to a hydrogen transportation economy is unlikely without a strong government involvement in selection of technologies and implementation of those technologies. "In the U.S. hydrogen is not well integrated with the national energy policy, partly because of reluctance to address petroleum import dependence, an uncertain stance toward climate change, and the bias toward more established energy sources."[47] Bush's energy initiative is attempting to address some of these inertial issues, but the resistance to movement is immense.

Currently, the Bush Administration is preoccupied with events in Iraq. Barring a major, unforeseen disruption in oil and gas imports, it is doubtful that sufficient government attention will be focused on the transition to a new energy carrier until the situation in Iraq is resolved.

This raises an important question. Putting the United States' involvement in Iraq aside, what should be the role of government in the lives of those living in a capitalistic society? Should government get directly involved in private lives except in the case of a national emergency?

CONCLUSION:

Upstaged by the events following 9-11, the energy policy, which was one of the highest priorities of the Bush Administration, if not the highest priority, has taken a back seat to issues of national security. I contend that establishing a well-coordinated energy strategy, with carefully laid plans for implementation, is the basis for national security itself. What would happen if oil supplies are interrupted in the future, as they have been in the past with just minor kinks in the supply pipeline, and we don't have enough gasoline, jet fuel or diesel fuel to drive our automobiles to work, to get to our business meetings by airplane, to steam our combat ships, or to drive our military vehicles? Whereas the President has increased Department of Energy funding for research and development of alternate energy sources,[48] overall government funding for research and development of alternate energy sources has decreased over the past three years.[49] Not only do we have an ends and ways mismatch to the President's own energy strategy, there is an ends and means mismatch with the overall energy strategy of the United States. Although some innovative ideas have been identified to ameliorate the potential problems, no one is properly coordinating the enormous task before us and time is running out before the "energy crisis" identified in the President's energy policy becomes untenable and threatens to disrupt the life styles to which the American people have become accustomed. We need to directly implement a hydrogen economy. The question is not when we will run out of oil. Instead, we need to ask, will we run out of time before we develop an alternative to the oil driven economy?

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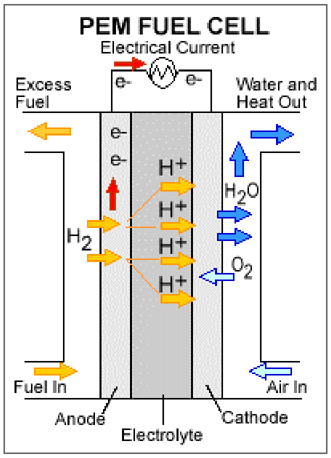

FIGURE 2 POLYMER ELECTROLYTE MEMBRANE FUEL CELLS COURTESY: DEPARTMENT OF ENERGY[50]

Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or onboard reformers.

Polymer electrolyte membrane fuel cells operate at relatively low temperatures, around 80°C (176°F). Low temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to CO poisoning, making it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost. Developers are currently exploring platinum/ruthenium catalysts that are more resistant to CO.

PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

A significant barrier to using these fuel cells in vehicles is hydrogen storage. Most fuel cell vehicles (FCVs) powered by pure hydrogen must store the hydrogen onboard as a compressed gas in pressurized tanks. Due to the low energy density of hydrogen, it is difficult to store enough hydrogen onboard to allow vehicles to travel the same distance as gasoline-powered vehicles before refueling, typically 300-400 miles. Higher-density liquid fuels such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline can be used for fuel, but the vehicles must have an onboard fuel processor to reform the methanol to hydrogen. This increases costs and maintenance requirements. The reformer also releases carbon dioxide (a greenhouse gas), though less than that emitted from current gasoline-powered engines.

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So, what do we do? I'm not sure but if we, the USG and the Big Three, don't get our collective act together, does it mean anything for the economic prosperity and competitive posture of the nation. How does this relate to defense issues? No idea what the answer will be but in recent months the

Big Three have come to realize that maybe their cooperative umbrella R&D organization, USCAR, can and should have a bigger role in fostering cooperation between the OEMs and USG. I have no idea what the direction will be but I do know that USCAR, which has traditionally chosen its director from the ranks of the OEMs on a rotating basis is seeking a new director with closer ties to DC and who understands the industry but is not bound to any particular manufacturer. More importantly, if such a shift is possible, can the U.S. even tolerate such a fundamental shift. So, back to my question, what's needed? Obviously we can't follow the example of our Chinese friends but what about a focused USG-industry effort comparable to MITI? If not that, should we let Dearborn, Warren, and Auburn Hills continue to go it alone as we're doing now and put up with consequences? What about a USG-directed NASA moonshot equivalent to boost technology. Dependent on choice, what are the economic, defense, industrial, and environmental consequences? What will or should the national landscape look like in 2100? What has to be done now to get there? A century ago, the United States was engaged in a well-documented, highly-hyped conflict with Spain that shifted to guerilla war in the Philippines. Meanwhile, some folks in Detroit were pursuing change of a different sort that also has had a fairly significant impact on our lives today.

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