The Green Hydrogen Paradigm Shift

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ABSTRACT

The change from a global economy dependent upon fossil fuels to renewable fuels for an hydrogen economy is occurring now. Not in 50 to 60 years, but the hydrogen economy is underway today. This "paradigm shift" is one as significant and dramatic as the Industrial Revolution itself. And more importantly, it is not an adjustment or cycle or bubble. Indeed, the hydrogen economy is upon us now, and every nation and community is now experiencing the transitions therein.

This article addresses that paradigm shift but also the immediate economic and business development for any region or nation-state. More significantly, when the production of hydrogen is derived from renewable energy resources, not only are there societal benefits but also sustainable economic growth. Some of the immediate evidence can be seen in California, where "civic markets" are indeed working, but also with the combination of infrastructures into hybrid systems. Herein the combination of hydrogen for stationary power with transportation fuel needs is expediting the paradigm change into economic feasibility today—not in the next Century.

INTRODUCTION

One of the clear pathways to a paradigm change (Kuhn, 1962) is the "hydrogen economy". In early 2001, Shell (2001) looked at the transition to hydrogen as early as 2010 and rapidly its becoming the dominant fuel source within 10 years thereafter see (see Figures 1, 2 and 3). President Prodi (2002) and his advisors (Rifkin, 2002) have advocated policy makers to embrace an "hydrogen economy". But it took President Bush's State of the Union Address in January 2003, to accelerate the worldwide level of activity surrounding "hydrogen and fuel cells". The

Economist proclaimed "the end of the Oil Age" in October 2003 (pp. 11-12). Then Governor Schwarzenegger made reference to a potential hydrogen economy in California in his fall 2003 campaign for Governor, but was far more adamant in his State of the State Address (2004b). Then in late April 2004, Governor Schwarzenegger announced "California's Hydrogen Highway" (2004c) and signed an Executive Order empowering state resources and staff to work on implementing this vision.

However, recent literature and pubic promotional claims, notably from Dr. Joseph Romm (2004b), have caused both consternation and re-evaluating about the hydrogen economy along with some hesitation among decision-makers. The truth is that the real "hype" to a hydrogen economy comes from the American-centric research and industrial communities. The arguments made by Romm (2004a) and others are primarily to support, bolster and advance a multi-decade research and development agenda advancing but actually maintaining the status quo fossil fuel paradigm. Sperling and Ogden (2004) refuted some of the claims made by Romm but left unchecked the strong impression that hydrogen was decades away. Their view was only that hydrogen was

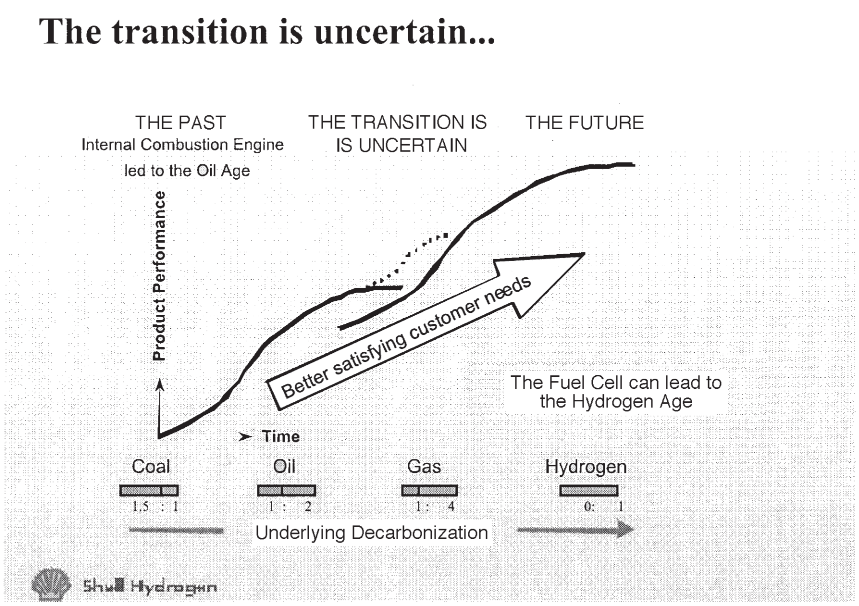

Figure 1. Green Hydrogen: Challenges and Opportunities (Source: Shell Hydrogen)

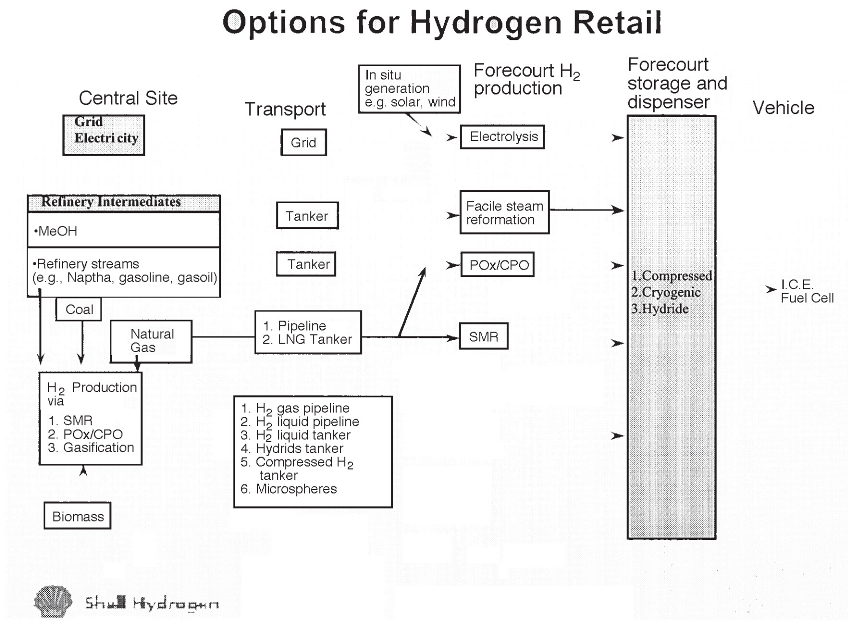

Figure 2: Options for Hydrogen Retail
(Source: Shell Hydrogen)

the best option for the long term.

The reality, as Rifkin (2002), Clean Coalition (2004) and the Foundation on Economic Trends Science and Technology Team have argued (FET, 2004) is far different: clean and green hydrogen is available at reasonable costs today. While the American National Academy of Sciences (2004) and Research Council each argue that hydrogen is still too costly, the opposite is true. And in fact, the costs of hydrogen today are comparable to the costs for the commercialization of any new technology, be it the internet or mobile phones. Like any new innovation and advanced technology, the initial costs for renewable generated hydrogen are a bit higher now but will shortly be far below (especially when calculating the renewable fuel costs) current market prices.

Hydrogen has captured the research and business community's imaginations since the mid 1800s as a fuel for motors and industrial use. According a history of hydrogen included in Peter Hoffman's book, Tomorrow's Energy (2002:29), Jules Vern wrote in 1874 of the possibility of using water broken down into hydrogen and oxygen by electrolysis

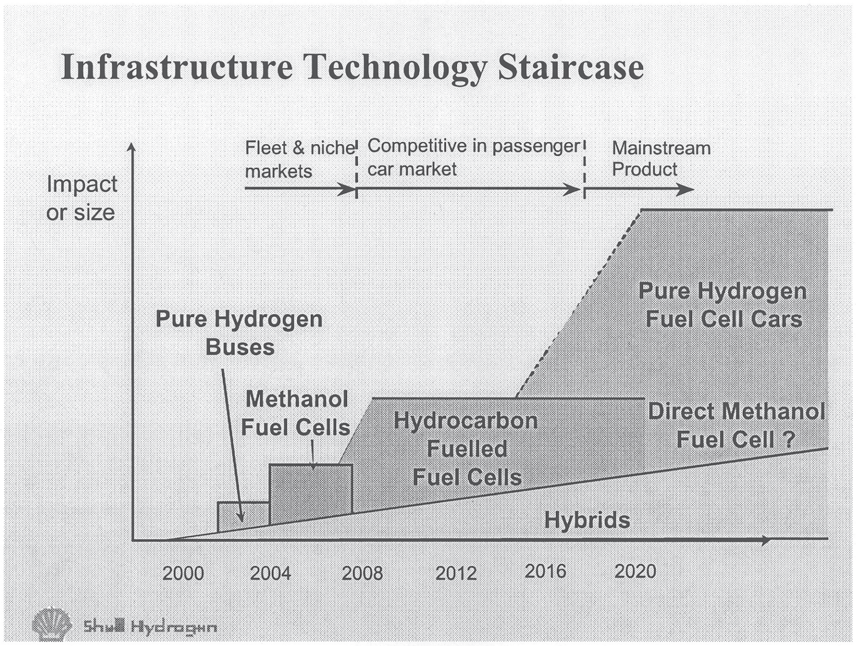

Figure 3: Infrastructure Technology Staircase (Source: Shell Hydrogen)

as the "fuel for steamers and engines! Water to heat water." The future was clear, but it took over a century to become real.

German and English engineers worked on using hydrogen along with gas or diesel in combustion engines during the 1930s. Applications were made to airplanes, submarines, torpedoes, trains, and other uses. It did not take much visionary thinking to see the value of hydrogen in producing weapons. Fuel cells increased interest in hydrogen in the 1950s, after Francis Bacon, a British scientist developed the first practical hydrogen-air fuel cell, a design that would be of interest to the U.S. space program.

By the mid-1990s, the Ballard fuel cell, and realization of the dangers of global warming, led to further popularization of hydrogen. Several articles appeared in The Economist, and Science that promoted hydrogen as the fuel of the future. Hydrogen is plentiful, clean and harmless. Moreover it is safe, contrary to myths (Hoffman 2002; Lovins 2003; Clark 2004b). A number of academic research units and corporations have invested considerable resources to document the safety of hydrogen, among them

Norsk Hydro (2003), Stuart Energy (2003), along with many government and non-government organizations (CFCP 2003).

By the late 1990s and early, the Economist was clearly seeing a paradigm shift, if not a revolution in fuels and energy (1997c, d; 1999a; 2000; 2001b; 2002a, b and 2003), then in the economics of the new and advanced technology markets such as fuel cells and hydrogen. These and other technologies were finally emerging from the research laboratories and becoming ready for commercial markets (Isherwood et al. 2000; Lamont et al.1999, 2004; LLNL 2003). Academic institutions such as the University of California, Davis with its Institute for Transportation Studies saw fuel cells and hydrogen rapidly moving into the market place (Sperling and Ogden 2004; UCD ITS Web Site); as did the University of California, Irvine, National Fuel Cell Center (Samuelson 2004 and UCI Web Site).

The State of California also took the lead in the fuel cell and hydrogen fields through the implementation of "civic markets" (Clark and Lund 2001) whereby public and private partnerships are formed through meetings to discuss barriers to commercialization as well as solutions for implementing adaptation of advanced technologies. Often the public sector becomes the initial market driver, as is the case with the California Hydrogen Freeway through regional and state wide air quality boards and public highway departments. (Clark 2003).

Jeremy Rifkin (2002) has perhaps done more than any other contemporary author to document and provide some definite direction too how hydrogen public policy could be developed. His book, The Hydrogen Economy (December 2002), provides the "translation" from science and technology into policy making language, which allows decision makers to move far more rapidly into implementing "Hydrogen Economy(s)" globally. Within a month of Rifkin's book release, it was translated into several languages. The impact was global. For example, President Prodi of the European Union, who had been aware of Rifkin's work in environmental and hydrogen policy, asked Rifkin to serve as an advisor to the EU (Rifkin 2004).

California, meanwhile was addressing head-on its infrastructure future needs through the Commission 21st Century (CCA 2002), with hydrogen as one part of the solution in a distributed energy generation model. The proof will be California's ability to set a course for the future, which is both ubiquitous and responsible for all its citizens. Maintaining and increasing environmental goals will always be a cornerstone for

California decision-makers, as the public consistently supports strong regulations and controls on the use of the State's natural resources. In that context, California continues to lead the world in providing a clean sustainable energy future.

Governor Schwarzenegger promised (2004a, b) to aggressively pursue the hydrogen economy and its highway. The pivotal issue for hydrogen will be the kind or source of the hydrogen. Hydrogen is simply a carrier of energy. It requires fuel to be converted into hydrogen. As discussed in more detail below, hydrogen will be seen as produced from either renewable or fossil/nuclear fuels? At this point, suffice it to say that the technical and economic links between renewables and hydrogen are not only critical challenges, but also enormous opportunities (FET 2004).

Increasing numbers of studies are examining both the technical and economic relationships between renewable energy and hydrogen. Berry (1996) was one of the earliest to make the connection, which was followed by the studies that he helped to lead at Lawrence Livermore National Laboratory in the mid-1990s (Berry et al., 1999) followed by others (Isherwood, et al. 2000; Kammen and Lipman, 2003). Berry's conclusions about renewables and hydrogen are significant and since 1999, the economics have improved by sector factors:

> Hydrogen can be used to facilitate the introduction of renewable energy resources since it can be used as both an energy carrier and a storage medium to compensate for the intermittency of many renewable resources. Using renewable resources and hydrogen we can serve both the electric sector and the transportation sector. It has been suggested (Berry 1996) that there may be a synergy between the transportation and electric sectors when renewable resources are used. This section investigates the possibility of such a synergy (Berry et al. 1999:4).

Indeed, a hydrogen economy exists today. What a California Governor's office hydrogen forum revealed in August 2003 (Clark 2004a) was that while research and development is always desirable as part of public policy making, there are numerous companies and communities who want and can implement hydrogen infrastructures, vehicles, and stations now" (Clark 2004a). Hydrogen is "apolitical," and the need to implement a hydrogen economy is neither political nor unattainable.

The report from this forum substantiates that a "consensus developed" among government officials and industry leaders whereby California in particular, but any nation-state, to achieve energy independence must commercialize innovations and technologies to serve its social, economic and environmental goals. "Hydrogen is one such 'leveling' or bi-partisan innovative technical advancement" (ibid. 1). While President Bush predicted in his January 2003 Sate of the Union Address that hydrogen and fuel cell vehicles would be available for his grandchildren to drive (20 years away), the "competition" globally is occurring today (Abrahams, 2003) as the EU responded to the International Ministers Conference called by Abrahams in Washington DC in November 2003 to plot a near-term global hydrogen economy (October 2003a, b).

President Prodi puts it more to the point. Either the EU "sinks or swims" (2003) in competing for hydrogen markets now. Hence, he personally has taken an interest in the hydrogen economy and the European community has allocated billions of Euros to funding research, deployment and procurement of hydrogen based commercial products and services. It is no accident that Rifkin (2003) has been engaged in working with the European Union.

Nor is it an accident that the group of over 50 representatives from academia, industry and government at the California Hydrogen Forum, during the summer of 2003, and many of the 200+ people attending a U.S. Department of Energy and University of California, Davis, Institute of Transportation Summit in Asolimar, California, clearly acknowledged that hydrogen businesses are prepared today to advance the hydrogen economy into the marketplace in tandem with continued research, development, and standards. Much the same conclusion came from a high-level group report at the EU in June 2003 (June 2003). Thus, the future for hydrogen is now and not in 20-30 years (Garvin 2003).

Hydrogen is plentiful and businesses exist today that commercialize it (Ogden 1999 and Swisher 2002). As the scientific community might phrase it, the research and development community proceeds in its linear scientific methods, but more non-linear and hence parallel safe and clean hydrogen technologies exist today that avoid the "chicken and egg" syndrome. The best example is the recent misstatements and serious questions about assumptions from researchers at Cal Tech over the negative impact of hydrogen on the ozone (Tromp et al. 2003). Despite some skepticism and debate from Tromp et al. (2003; Keith and Farrel 2003) the counter arguments from others (Kammen and Lipman 2003;

Sperling and Ogden 2004), validate the hydrogen future as being "now" and not 50 years from the early part of the 21st century.

THE "PARADIGM" SHIFT

As Clark (2003a, b, 2004a) summarized the hydrogen economy, it is the next "paradigm shift" now under way as a major change in the way California policy makers and industry are looking for clean fuels and energy for the state. Current volatile gasoline prices, growing demand especially for natural gas, and the national and international energy / environmental crises are motivating this shift. The Economist perhaps put it best in October 2003 with the front cover title "The end of the Oil Age" and article (*Economist* October, 2003: 11). Here, the argument was made that for the developed or even developing world to continue their dependence on fossil fuels would be a continued source of world conflict. A new fuel-based world order was needed.

Indeed, fossil fuel supplies are decreasing in California (CEC, 2003) and elsewhere to no more than 50 years of reserves even by conservative standards (Anderson, 2000). The entire country of Norway, now the second largest oil and gas producer in the world, has national legislated a shift in priorities from fossil to shift to other fuel sources. The future, however, for the hydrogen paradigm is also mired in conflict. As noted above with the reports from Romm (2004) and Tromp et al. 2003), critics appear to confirm President Bush's contention in his State of the Union address (2003) that hydrogen is really several generations away.

American industry has echoed these sentiments and misinterpretations. For example, a series of advertisements throughout 2004 in the international press from General Motors (2004) further promotes that perspective. The ads talk about a hydrogen economy—in the future with a full page photo ad titled "Who's Driving the Hydrogen Economy" with two little children (an enfant and 2-year-old) playing on a toy car and hence implementing that they or their children (almost a direct paraphrase from President Bush) will see and benefit from the hydrogen economy.

Shell, however, and some other oil and gas companies have been far more aggressive in pushing for the hydrogen economy, albeit one based on "fossil fuels". Shell (2001) addressed the challenges and opportunities for a hydrogen economy with the conclusion that it was worth the investment. As Figures 1-3 indicated, unlike GM, Shell sees the hydrogen coming rapidly into the marketplace. Shell has numerous demonstration efforts in Iceland and throughout Europe as well as California, primarily in partnership with major automakers.

On the one hand are the "green hydrogen" advocates (GHC 2003) who argue that hydrogen must be derived and produced only from renewable energy sources. While the costs today for renewable hydrogen production is higher than fossil fuels, they are rapidly become cost competitive and market based, as researchers over the last five years have successfully documented (Berry et al. 1999; Ogden 1999; Lipman and Kammen 2003; Lamont et al. 2004). Berry et al. summarize the potential in the late 1990s as:

> These analyses identify the most economic ways of serving a given set of energy demands (electricity and/or transportation fuels) from a given set of resources (renewable and conventional). In each case, the quantities of energy to be served every hour and the types of resources available are specified. The analysis then determines the most economical system configuration (sizing the various components of the system) and operation to meet these demands using the specified resources.
>
> Correctly evaluating the costs of a case requires a two-stage optimization: the configuration of the system must be optimized and, for each configuration, the operation of the system must be optimized. We optimized the configurations by trial and error, altering the configuration until a minimum cost was found (Berry et al. 1999:4)

Since this study, one of the most effective ways to address the economic issue is through what has become know as "hybrid" technologies (Isherwood et al. 2000) or where two technologies are combined and hence increase performance while saving on costs (Lagier 2003). Hybrids are covered more thoroughly elsewhere in this article. However, a number of both academic and practical examples document these advantages (Clark 2003, 2004).

The other approach to hydrogen can be called "dirty" or "black". The U.S. government and many large oil producing countries and companies advocate fossil fuel or nuclear based hydrogen production. The U.S. government has allocated over $1.3 billion (USD) to hydrogen research, development and collaborations with almost $750 million (USD) in new funding. Most of these funds, however, are directed toward fossil fuels, nuclear and clean coal technologies. The 2004-2005 Energy Bill in the U.S. Congress is also skewed in this same direction.

What is important to note here is that the production of fossil fuels and now the production of hydrogen from natural gas have had a long history similar to the green hydrogen model. Historically gasoline and diesel fuels also cost more when first introduced in the market. Moreover, some of the most aggressive hydrogen producers today are the same oil and gas companies who also produce dirty hydrogen. They see, for example, natural gas through reforming technologies as the immediate future for producing hydrogen. As Berry et al. (1999) point out:

> We consider a pathway to introducing hydrogen based electric generation to the power grid. We first consider a base case that is entirely powered by conventional technology: a natural gas turbine. Then we consider several variations. The first variation replaces 40% of the natural gas generation with a fuel cell. Hydrogen for the fuel cell is generated using a natural gas reformer. This case allows us to compare the costs of the two systems. (Berry et al. 1999:20)

The issue of dark or dirty hydrogen is significant for a number of reasons. Consider, however, only the economic and competitive ones. The EU is advocating a "dual" policy but heavily weighed toward the green hydrogen. The GHC makes the same point (November 2003b). In essence, hydrogen derived from natural gas is perhaps the best transition to a hydrogen economy. According to a study by the California Office of Planning and Research (2004) and the CA Fuel Cell Partnership (2000), "Globally, proven natural gas reserves are estimated at 60 years or more of projected use, and even 100 million HFCVs (20% of the vehicle stock in all developed nations) would add only about 2% to projected consumption in 2025." (2000:4-14)

The same Directed Technologies study cited earlier showed that over the next 40 years, if hydrogen were produced solely from natural gas and no other sources, there would be between an 8 to 11% increase in demand. For example Ogden's early study (1999) of the Los Angeles area reports:

> Ample natural gas resources are available in (Los Angeles) area to produce hydrogen transportation fuel in the near term. Fueling a

> fleet of 200,000 fuel cell cars and light trucks plus 330 fuel cell buses would require about 26 million scf hydrogen/day. This amount of hydrogen could be produced via steam reforming from about 8 million scf/day of natural gas or about 0.3% of the total natural gas flow through Southern California Gas's distribution system (which carries about 3 billion scf natural gas/day) (1999:715).

The bottom line issue is that in the Los Angeles area, there already exists adequate resources and industrial capacity to produce enough hydrogen to start the hydrogen economy. In addition, the economics and investment required is well less than many other energy projects such as liquefied natural gas (LNG) ports running between $3 to 5 billion (USD). This does not include the costs for transportation either by pipeline, highway or other means. The hydrogen paradigm allows a rethinking of priorities and investment in strategies that will have long term benefits of agile energy.

GREEN HYDROGEN ENERGY STATIONS

The pathway to commercialization is through hydrogen "green" energy stations (Clark 2003, Clark et al. 2005). The hydrogen freeway is now under construction in California and leads the world in the number of hydrogen refueling stations. Southern California through the South Coast Air Quality Management District (SCAQMD) has aggressively taken the lead because the need and demand in Southern California are extraordinary. Hydrogen energy stations are the most economical and efficient approaches to get clean hydrogen into common use and therefore, create new markets and businesses. SCAQMD and private corporations (Clark 2004a) have all indicated that the "energy station" for power and fuel is the most viable and economic approach to commercializing hydrogen.

Hydrogen can be stored on-site in homes and businesses and then used during times of day when grid connection energy is expensive. Or hydrogen can be stored and simply used for all power needs. Stuart Energy (2003) introduced in 2003 a small electrolyzer system for such applications. Other companies are certain to follow suit.

The transportation of hydrogen is currently by pipeline or by roadway via cylinders, tube trailers, and cryogenic tankers, with a small amount shipped by rail or barge. These pipelines, which are owned by merchant hydrogen producers, are limited to a few areas in the U.S., where large hydrogen refineries and chemical plants are concentrated, such as Indiana, Southern California especially near the ports of Long Beach, Los Angeles and San Pedro, Texas, and Louisiana.

The locations coincide with the oil and gas production, refining and storage facilities near ports. Hence, despite the official reports on the increased demand for natural gas and the future need for hydrogen (CEC 2003) one of the major reasons for California being pressured to allow liquefied natural gas to be shipped, refined, stored and transported is to accommodate the oil and gas companies.

Herein lies the next problem in the hydrogen economy. Hydrogen is distributed via high-pressure cylinders and tube trailers that have a range of 100 to 200 miles from the production facility. For longer distances of up to 1,000 miles, hydrogen is usually transported as a liquid in super-insulated, cryogenic, over-the-road tankers, railcars, or barges, and then vaporized for use at the customer site. Hydrogen can be stored as a compressed gas or liquid, or in a chemical compound. The environmental dangers are apparent, but the safety and security risks are far more compelling.

Hydrogen refueling stations and the creation of a "hydrogen freeway" are essential to creating a cost competitive hydrogen infrastructure. The statistics today eliminate the "chicken and egg" argument that hydrogen is not cost competitive because of its high operating and maintenance costs. Hence, hydrogen will need another 15 to 20 years in further research to bring down the costs to commercial and mass market levels.

Yet these hydrogen stations can be operational in homes and businesses. They can be modeled after current retail fueling stations, but also supply power for the local community homes, stores, and businesses. Linking Los Angeles and San Francisco via a "hydrogen freeway" is an important symbol for showing the vitality of the hydrogen economy. But more importantly, it can be commercially done.

Cal Trans and SCAQMD have focused on the hydrogen energy station approach. Several industrial partners have done so likewise. Toyota has done cost planning analyses demonstrating the practical and economic benefits. ChevronTexaco has contracted for economic and business models studies as well.

To have a hydrogen economy and hence the concomitant infrastructure, one of the central elements is setting "standards, codes and protocols" for safety, security, fire and even business case certainty. California did as much with the Zero Emission Vehicle (ZEV) requirements in the 1990s. Governor Davis did so again in 2002, by signing the "greenhouse gas" (parallel and even stronger than the Kyoto Accords) bills. When society sets "high" goals and standards, civic markets are both endorsing societal values and being economically competitive.

Building "Hydrogen Highways" across America, which then supply fuel for the hydrogen vehicles now and those coming to the market soon, should also provide power for homes, businesses and public buildings. These new infrastructures are not far away in the future. Again the fuel source is important. For example, in California, there is an abundance of renewable energy fuels like sunshine, wind and geothermal. But in other parts of the U.S., there are other more abundant fuel sources such as clean coal, oil and gas.

Nonetheless, renewable energy sources should be the primary policy goal for sources of hydrogen fuel production to be used for onsite and grid connected power. When one or more technologies, like wind and hydrogen production, are combined, the costs of these hybrid technologies is greatly reduced (Isherwood 2000; Clark 2003; and Lagier 2003). See below for further discussion and details from CEC on the potential of hybrid technologies (CEC 2003, website:http://www.energy.ca.gov/reports/index.html). Renewable energy sources can be reliable and "firm load" when used as "hybrids" such as solar photovoltaic (PV) with hydrogen fuel cells (Clark and Morris 2002; Lagier 2003). Clean energy is good for the environment and the health of human beings, especially children. The California Power Authority "Clean Energy" report and program at website www.capowerauthority.ca gives further details on actual financial costs for renewables.

Furthermore, hydrogen energy stations can be the solution to environmental justice issues. For example, in San Francisco, a case has been made when the local community rallied around environmental justice issues to create clean power generation sources to replace dirty 40+ year old power plants. Community leaders embraced hydrogen energy stations and even advocated wind turbines off the South San Francisco former Naval ship yard as one source for renewable energy production.

Further, the San Francisco city and county, as noted earlier, passed a $100 million bond measure to provide solar/PV systems to public and private buildings. Linked with the production of hydrogen, significant economic and technical issues will be solved. Honda, recognizing this strategy, has offered two leased (at a discount) hydrogen fuel cell cars to the city government.

The change and action that create "empowerment" at the local level, such as San Francisco, Los Angeles, Santa Monica, Berkeley, and Pleasanton to name only a few and through regional organizations like SCAQDM have taken the national lead in creating a hydrogen infrastructure. The general public policy is known as distributed energy generation and needs to be seen as flexible energy systems with the "agile energy infrastructure systems" advocated in this volume. Basic information on distributed generation can be found with the CEC at website, among other places, at www.energy.ca.gov/distgen/strategic/strategic_plan.html.

When energy systems are seen at the state or multi-state level, they are "agile energy infrastructure systems" because they combine local on-site power generation (www.cpuc.ca.gov/PUBLISHED/REPORT/13690.htm) (e.g., solar power for hydrogen energy stations supplying both power and fuel) with grid energy and fuel resources (e.g. hydroelectric and wind for hydrogen storage). Note now that the California ISO, with its Tariff approvals from the FERC, were able to get the imbalance rules changed (www3.ferc.gov/) such that the storage of hydrogen for future peaking and as base load creates a new firm energy supply from renewable generated resources.

Government lead initiatives and programs greatly expedite the reality of the hydrogen economy. Government fleets should have specifications that require hydrogen conversion of internal combustion engines that set goals of hydrogen fuel cell vehicles. Livermore National Labs scientists estimate (Clark 2004a) it will take 100,000 vehicles for the hydrogen economy to become financially fueling self-sustainable.

Implementing the hydrogen economy can further help the State to achieve its renewable portfolio standard (RPS) goals, such as the 20% goal by 2017 (but will be at that goal by 2010). Several European countries have set goals higher, such as Denmark for 50% by 2020; and Governor Schwarzenegger with 20% by 2010 (www.energy.ca.gov/renewables/documents/legislature.html)

Berry et al. (1999) "address(es) the question of increased efficiencies from combining transportation and electric generation (when) we determined the sum of the costs of separate systems—one serving electric only and one serving transportation only—and compared it to the cost of a combined system." (1999:11). Perhaps Rifkin (2003) put it best:

> The real benefits of a hydrogen future can be realized only if renewable sources of energy are phased in and eventually become the primary source for extracting hydrogen. In the interim, the U.S. government should be supporting much tougher automobile fuel standards, hybrid cars, the overhaul of the nation's power grid with emphasis on smart technology, the Kyoto Protocol on global warming and benchmarks for renewable energy adoption (Rifkin 2003, Commentary).

Hydrogen is a good example of hybrid technologies (Lagier 2003, Clark 2003). Hydrogen can be supplied through either electrolysis or through reforming. Both compressed gas and liquid hydrogen storage have been included. The energy penalty for liquid hydrogen storage is 3 to 4 times that of compressed hydrogen, but its capital cost is only 5% to 10% as much. This makes liquid hydrogen storage the most useful for long term storage when large amounts of material need to be stored in one season and released in another.

GREEN HYDROGEN: THE RENEWABLE OPTIONS

There is another way to produce hydrogen—one that uses no fossil fuels or nuclear power in the process. Renewable sources of energy—solar photovoltaic (SPV), fuel cells, wind, small sustainable hydropower, geothermal, and even wave power— are technologies that are available today and are increasingly being used to produce electricity. That electricity, in turn, can be used through the electrolysis process to split water into hydrogen and oxygen. According to several analysts (Hoffman 2002; Rifkin 2002) the efficiency of electrolysis is around 80%, which means that nearly all the energy value of the electricity can be stored as hydrogen. Clearly this is a positive factor given the importance of finding a way to store electricity, because it must be used later or at peak hours once it is created.

Hydrogen generation with electrolysis allows storage of intermittent production of renewable energy, which solves one of the key problems of renewables discussed throughout the book. Because some of the electricity being generated can be used to extract hydrogen from water, which can then be stored, for later use, society will have a more continuous supply of power. As Berry et al. (1999) put it in economic terms, the combination of SPV and hydrogen production leads to "savings in several areas and the results suggest that the SPV capacity would be cost justified in its own right. However, we also note that adding the SPV capacity changes the LDC for the fuel cell. "Further savings could be obtained by adding a fuel cell that has low capital costs, even if its efficiency is quite low" (Berry et al. 1999: 20). With the costs of fuel cell construction and operations rapidly declining annually by a factor of two (SFCC 2003), the total costs for hydrogen and its low costs for the market will make it extremely competitive in a short time.

Clean biomass, which includes non-genetically modified sustainably grown energy crops and sustainably retrievable agriculture wastes, could also be an important near-term source of hydrogen for fuel cell vehicles and electricity generation. Clean biomass is a proven source of renewable energy that is utilized today for generating heat, electricity, and liquid transportation fuels.

Furthermore, clean biomass can be used to produce hydrogen through a process called gasification in which the biomass is converted to a gas and hydrogen is extracted. Virtually no net greenhouse gas emissions result from these biomass processes because a natural cycle is maintained in which carbon is extracted from the atmosphere during plant growth and is released during hydrogen production. Replanting and reforesting are prerequisites for maintaining a renewable hydrogen supply from biomass.

The potential of new technologies for storage also are promising. For example, the promise of the production of hydrogen from renewable energy comes from wind developers themselves. In personal discussions Romanwitz (2002), the CFO at Oak Creek in California stated:

> Conventional pumped storage has a capital cost of around $1,500 per kW and a turn around efficiency of around 72%. The concepts that I am working on are anticipated to provide a very substantial improvement to those numbers both in terms of capital cost and in terms of better efficiency… other storage technologies have costs and performance in that same range, such as compressed air and the chemical storage of ionology… Ion exchange technologies may be more cost effective and efficient by a significant margin (Romanwitz 2002:1)

USING HYDROGEN FOR VEHICLES

Once produced, hydrogen can be stored and used, when needed, to generate electricity or be used directly as a fuel. Storage is the key to making renewable energy economically viable. It is worth noting that both Toyota and Honda in their North American Headquarters in Torrance, CA, produce hydrogen from their SPV electricity systems and operate hydrogen refueling stations for their fleet of hydrogen vehicles. Most of the analysts feel that the best use of hydrogen produced from renewable sources now is to use it directly in applications where it can be delivered to the place needed, rather than installing utility scale generators that turn the hydrogen back into electricity for the grid. The most appealing use of hydrogen is in vehicles, where the fuel cell gets higher efficiencies than gasoline combustion engines and delivers the power where it is needed on the highways.

One of the major challenges facing the world's urban areas is atmospheric pollution caused by the internal combustion engine. In recognition of this, the United States passed the Clean Air Act in 1990 requiring that 22 major metropolitan areas improve their air quality or lose federal funding. The Los Angeles basin area, with a population of over 10 million people and surrounded by a crescent formation of mountains at the edge of the Pacific Ocean, was the catalyst for the state taking some action to clean up the air.

Beginning in the late 1980s and for six years, the California Air Resources Board (CARB) sponsored a state-wide inquiry into a proposed set of regulations that initially required car manufacturers to sell 10% zero emission vehicles (ZEV) starting in 1998 with increasing percentages every two years thereafter. This series of regulations has since been adopted by 12 other states and the District of Columbia, and is expected to be adopted by 11 other states.

These regions represent 40% of the U.S. automobile market. Now other countries in Europe and Asia are adopting similar regulations. While the regulations have been modified to adjust to industry concerns, the percentages of ZEV automobiles expected to be delivered to each category are: utilities 90%; Federal 70%; State 50%; businesses in non-attainment areas 50%; other businesses 22%. This totals 925,000 fleet vehicles in 2003. While CARB action over the summer of 1996 allowed the auto manufacturers some flexibility in meeting the deadlines, the basic regulations remain and will be enforced and not greatly compromised in the future.

Meanwhile in 1999, CARB initiated the formulation of the California Fuel Cell Partnership (CFCP) as a government and private sector association. The Partnership is located in West Sacramento with a facility for all international manufacturers. Its recent strategic plan called "Bringing Fuel Cell Vehicles to Market: scenarios and challenges with fuel alternatives" (2001) calls for a variety of perspectives for the commercial implementation of vehicle fuel cells in California (Bevilocqua 2001). Aside from environmental regulatory legislation, there is an inherent market demand for energy generation and storage devices. Pollution free power systems using fuel cells appear to be the best long-term solution (Isherwood et al, 2000). A hydrogen refueling station was installed, for example, at Los Angeles International Airport in 2003 under an aggressive South Coast Air Quality District (SCAQMSD) program, which provides almost 50% of the financing.

By the end of 2003, another six stations were awarded matching funds. The same technology push for hydrogen and fuel cells will assist shipping companies, where their vessels are docking and loading in port areas, are also under local pressure to eliminate pollution arising from their idling engines while in port. Iceland is leading the world in developing demonstration sites for fishing vessels.

California is pioneering the way for fuel for vehicles operated in fleets but available for the public. The State with local communities is also advancing hydrogen energy stations that provide power for urban shopping business districts, at airports, and in public parks, such as Yosemite. These hydrogen energy stations will provide power for local communities in anticipation for the growing demand from fleet vehicles and private citizens, which is anticipated to grow in 2004 and beyond.

Additionally, these commercial applications favor the economics of electric propulsion in stop-and-go, high standby driving profiles. Ironically, in a parallel market demand, the military needs large, silent, low-thermal profile vehicles, with peak power supplied by high rate batteries, ultra-capacitors or flywheels. The key is hybrid energy generation and fuel systems that rely upon renewable energy (Lamont et al. 1999; Northern Power 2002; Lagier 2003; Clark 2004b).

In spite of favorable market demands, large corporations and multi-national firms by themselves are reluctant to introduce new technologies; this process is often perceived as too risky and expensive. Instead, corporations appear to prefer a strategy that gives them a free ride in the marketplace, trying to "capture" profits from innovation introduced and developed elsewhere. Regulation may be necessary both to "force" firms to pursue innovation and social welfare, and to "coordinate technological research", according to government policy, where competitive advantages in the form of standardization and market dominance can be achieved. Shnayerson (1996) confides in his inside look at GMs development of the electric vehicles or EV1 that:

> the mandate (in California for ZEVs), by forcing the world's largest carmakers to start the hard R&D march to electric vehicles at a time when one but GM wished to do so, has been a triumph of social policy as important to the betterment of this country in its day as the Clean Air Act was a generation ago (Shnayerson 1996:xv).

Regulations also significantly affected Federal Government funding for developing new technologies. Federal government funded research in new technologies for substituting internal combustion engines (ICE) with fuel cells (e.g., the case at Lawrence Livermore National Laboratory) demonstrates the role of such national laboratories as opposed to industry R&D efforts. This is a very important role for federally funded R&D, because it solves some "market failures" and increases investment returns in terms of social welfare. Nationally funded R&D provides new technologies in a longer term perspective from 3 to 5 years as opposed to industries needs for 1 to 2 years and even less time in the software sector.

Nevertheless, in early January 2002, the U.S. Department of Energy Secretary Abrahams announced in Detroit and again at special session of the E.U. in Brussels (2003) that the U.S. would invest over $1.3 billion in hydrogen and fuel cells technologies. While scholars and journalists who closely watch the American government (Rifkin 2003) are skeptical about the intention of the U.S. government to focus research on the long term future of these technologies to derail the current federal antipollution regulations, the initiative is significant and a dramatic shift in public policy, which had been recommended by Partnership for New Generation Vehicles (PNGV) from the ICE development to new hydrogen infrastructure and fuel cell economy.

HYDROGEN TODAY: STATIONARY AND MOBILE APPLICATIONS

It is not enough for government to fund innovation, because research investments become irrelevant if there is no market. Government funds have to be coordinated to speed up innovation and to reduce its costs. This means creating markets as well as products. Evidence is mounting that the markets are opening up now and can be part of today's agile energy solution.

Corporate leaders are "bullish" on hydrogen and fuel cells, a dramatic change from only a few years ago (Clark and Paolucci 1997), when they either blocked or were skeptical about hydrogen. Some cynics argue that the major corporations (oil, gas, automakers, energy generators and others) are simply diverting attention from their real goal: maximize profits at all costs to society. Many environmental groups, for example, see the push for electric vehicles as a case in point, where the auto industry left both government regulators and consumers with public policies and guidelines unfulfilled. However, others (Clark 2004a), including former Chairman of General Motors, Robert Stempel (2002) noted that:

> The transformation to hydrogen power is underway. Major oil companies recognize this and have made significant investments in hydrogen systems, including better batteries using hydrogen (nickel-metal-hydride batteries), photovoltaics and fuel cells…
>
> The critics doubt such a sea change in the auto market can happen fast enough to make a difference. But Ford already has announced plans to launch a hybrid-electric SUV by the end of next year. Hybrid-electric-powered vehicles by GM and DaimlerChrysler are expected to follow suit. By 2005, some industry experts predict 3 million hybrid-electric vehicles on the road (Stemple 2002, Editorial).

The American news program, "60-Minutes" (Stalh 2003) ran a program in the fall of 2003 about the new GM HY car, which operates with hydrogen on fuel cell power and is in beta tests, but headed to the marketplace within the next five years (Brown 2003).

Many policy makers, including President Bush in his 2003 State of the Union see a far nearer term, such as 2020, for the introduction of hydrogen into the economy. Others, such as S. David Freeman see "Hydrogen Now" rather than even a decade away (Garvin 2003). Schwartz and Randall (2003) outline some of the basic steps that are leading to hydrogen development over the last decade in "10 Years of Energy Innovation":

1995

- General Motors rolls out an electric car, the Impact (later refined into the EV1), at the Greater LA Auto Show.
- GE introduces the H System, a natural gas-burning turbine that uses gas, steam, and heat-recovery technologies.

1997

- In Japan, Toyota unveils the Prius, the first mass-produced gas-electric hybrid.

1999

- Chicago spends $8 million installing solar panels in old industrial sites to light municipal buildings and parks.

2000

- The South African company Eskom begins construction on the first pebble-bed modular reactor, a safer kind of nuclear plant.
- Iceland declares itself the world's first hydrogen economy—major corporations (Diamler Chrysler, Shell, Norsk Hydro, etc.) focus technological demonstration projects there.

2001

- Clean Energy Systems develops a power plant that runs on natural gas and releases steam and carbon dioxide.
- State of California signs a memorandum of understanding (MOU) with Iceland to collaborate on the hydrogen economy with geothermal, fuel cells and other technologies.
- European Union announces its Clean Cities program—10 cities to have fuel cell (hopefully hydrogen) powered buses.

2002

- Honda leases the first of five fuel cell cars to Los Angeles. The 80-horsepower FCX's only emission: water.

2003

- Major car makers (now including GM) target California with new hybrid commercial (2004) and hydrogen fueled vehicles (estimated to be in 2006)
- U.S. DOE announces major request for proposal (RFP) on hydrogen

based technologies ($250 million) on President's State of the Union speech in January 2003.

- EU announces its plans on hydrogen under direction of President Prodi with a number of high level reports and funds (over 1 Billion Euro)—focus more on "green hydrogen"
- Ireland approves the world's largest offshore wind park, 200 turbines on a sandbank 15 miles long and a mile wide.
- California Governor Davis' Office of Planning and Research holds a public-private Hydrogen Conference in Los Angeles (August 2003)

2004

- Governor Schwarzenegger announces hydrogen freeway plans for California
- President Prodi initiates over 700 million (Euro) program
- President Bush announces $200+ million (USD) "winners" in hydrogen initiative
- Hybrid cars are in the mass market with hydrogen fuel cars expected in 2005

2005

- Japan installs hydrogen power stations
- Japan puts dozens of hydrogen fuel cell cars on the road
- California has a Hydrogen Highway Roadmap
- California cities and communities have "leased" hydrogen fuel cell cars: some from Japan and others from Germany
- South Coast Air Quality Management District has "five cities program" for hydrogen refueling stations with over a dozen more locations under consideration

The move to hydrogen infrastructures is moving ahead on a global scale. The European Union, for example, has announced in late 2002 a multi-billion (USD) program under President Prodi (EU 2002). The program is primarily geared to "clean fuels" (e.g., renewables, not fossil or nuclear) for producing hydrogen. This approach is in total opposition to what President Bush announced in his State of the Union address in late January 2003. Rifkin (2003) and others have pointed out that the Bush Administration means by hydrogen, fuel sources that are "clean coal", nuclear and natural gas. The vast majority of the $1.3 billion (USD) that Bush announced for creating an American hydrogen economy will go toward those fossil fuel sources.

Here we focus only upon the California case in part as a result of the need for California to provide solutions to its energy crisis in 2000 to 2002 (Clark 2001). We used optimistic estimates of the costs and efficiencies of various technologies including natural gas technologies, because this should give a more useful and robust picture of the trade-off between these technologies at the time that they may fully penetrate the market.

For example, both the California Power Authority's (CPA) Investment Plan and the Renewable Energy Plan for the Governor show that the costs for renewable energy technologies, such as wind but also solar and fuel cells, is cost competitive when seen in the aggregate, compared to fossil fuels, and purchased in large quantities. Similarly, Bolinger et al (2001) analyzed the bids received by the CPA for wind and geothermal power facilities to find that both technologies were competitive with traditional power resources.

Additionally the IGAWG's Standard Practices Manual (Schultz et al. 2001) showed that these technologies were competitive using a project financing life cycle analysis of new technologies, as well as externalities such as health, climate, and environmental impact. What has yet to be considered are the fuel source costs for development. For example, what does it cost to drill for oil or mine for coal compared to the use of the sun or wind (Weil 1991).

These cost analyses point out that the economic issue is closer than usually assumed. The technological innovations that will make hydrogen viable are not as far off as many critics think—at least 10 or 20 years. What these critics fail to recognize is both the fact that existing sources of energy are undervalued and the hydrogen economy is closer than most think to being cost effective even without subsidy. James and James (2001) show that electricity costs are undervalued in their research in the European Union's of "the true costs of electricity":

> The results of a major EU-funded study undertaken over the last 10 years and released in Brussels in July show that the cost of producing electricity from coal or oil would double and the cost of electricity production from gas would increase by 30% if external costs, such as damage to the environment and health, were taken into account. These costs amount to up to 2% of the EU's gross domestic product, not including any costs associated with global warming, and are absorbed by society at large rather than

> through the cost of consuming energy. The study was conducted by researchers in all EU member states, and in the U.S. It is the first study to attempt to quantify the damage resulting from all different forms of electricity production across the EU (James and James 2001).

In sum, the options for taking positive steps to introduce hydrogen into the economy now seem feasible. The demonstration of its viability is not at question, and gradually the affordability of hydrogen strategies is becoming less of an issue. What is now most important is the need to mobilize public efforts to create the markets and the incentives for firms to go through the long process of investing and perfecting technologies that at scale will become beacons for an energy hungry world.

CONCLUSIONS

The hydrogen freeway is being built now. Hydrogen fuel has advantages because it is derived from a number of sources. It is important to determine how hydrogen will be produced on a large scale. U.S. DOE estimates that large amounts of hydrogen are already in production in California and other regions in the U.S., but primarily from reformulated natural gas. Hydrogen can also be made from fossil fuel sources such as oil, coal and also nuclear, although each of these sources has both negative environmental impacts and serious waste problems.

Producing hydrogen from renewable sources is preferable from an environmental perspective but more costly than natural gas. Certainly other natural and renewable sources of hydrogen, such as geothermal, solar, water, wind, biomass and combinations thereof have been discussed above already. Hydrogen fuel sources can be leveraged from existing resources and areas such as State water projects. For example, the ability to store hydrogen in water pumping stations in the California Central Valley is staggering. Produce energy from wind or solar technologies and then store it. Furthermore, hydrogen can be produced from other abundant renewable resources like wastewater and biomass.

The role of government at all levels remains critical. It should be through a combination of policy, procurement, and transportation plans. State support of the hydrogen-powered vehicles can transform the nascent industry into a broad consumer market. Procurement of state vehicles is a critical first step in this process. Codes, standards and protocols are policy tools that will help the hydrogen economy grow.

Nonetheless, education and training of the workforce must be a central focus and concern. Beginning in the elementary but through community colleges for technical skills development and into the university for advanced training into the research institutions much needs to be done. Above all government can support the entrepreneurs who are turning ideas into new industries and businesses that are building the hydrogen economy

Finally, continued development and advances in hydrogen appear to be ready to mimic the telecommunications and life science fields. That is, public–private partnerships in these fields, often with substantial government funding, have proven to help the creation of new companies, and business sectors, and lower costs for all consumers. Hydrogen is about to launch onto the same pathway. And the commercial results will be even more dramatic.

Hydrogen is ready. Society is ready. Public policy makers must act now for the future of society.

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Woodrow W. Clark II, Ph.D., is a qualitative economist and has published a book on the California energy crisis from his work as senior renewable energy advisor to Governor Davis, as well as two other books and over three dozen referred articles on technology transfer, climate, energy, environmental and entrepreneurship issues. In 2005, Clark founded Clark Strategic Partners in Los Angeles, California, with clients including, the Milken Institute, Senior Fellow for Environmental (www.milkeninstitue.org); Energy Director for the Los Angeles Community College District; and Senior Foreign Energy Expert for Inner Mongolia in PRC (China).

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