An Integrated Hydrogen Vision for California

White Paper/Guidance Document

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Of course, the authors alone are responsible for the contents of this paper.

Abbreviations and Acronyms

ARB = California Air Resources Board
ATR = auto-thermal reforming
CAEATFA = California Alt. Energy and Adv. Transportation Financing Authority
CAFCP = California Fuel Cell Partnership
CAISO = California Independent System Operator
CASFCC = California Stationary Fuel Cell Collaborative
CEC = California Energy Commission
CHP = combined heat and power
COP = Conference of the Parties
CPUC = California Public Utilities Commission
DG = distributed power generation
DGS = Department of General Services
DOE = United States Department of Energy
EV = electric vehicle
FCV = fuel cell vehicle
GDP = gross domestic product
GHG = greenhouse gas
HEV = hybrid electric vehicle
INTI = Integrated Network of Transportation Information
ITS = Intelligent Transportation Systems
IOU = investor-owned utility
LEV = low emission vehicle
NAS = National Academy of Sciences
NOx = oxides of nitrogen
NRC = National Research Council
NUMMI = New United Motor Manufacturing Inc.
PG&E = Pacific Gas and Electric
PIER = Public Interest Energy Research
POx = partial oxidation
psi = pounds per square inch
R&D = research and development
RPS = renewable portfolio standard
SCAQMD = South Coast Air Quality Management District
SCE = Southern California Edison
SMR = steam methane reforming
UC = University of California
UNFCCC = United Nations Framework Convention on Climate Change
U.S. = United States
V2G = vehicle-to-grid power
ZEV = zero emission vehicle

Executive Summary

This paper concerns the economic and environmental challenges confronting California and the potential role for clean energy systems and hydrogen as an energy carrier in helping to address these challenges. Hydrogen in particular has recently gained great attention as part of a set of solutions to a variety of energy and environmental problems -- and based on this potential the current high level of interest is understandable. In our view, however, full realization of the benefits that hydrogen can offer will not be possible without a clear strategy for producing hydrogen from clean and sustainable sources and in a cost-effective manner. One of hydrogen's greatest benefits – having a wide range of potential feedstocks for its production – also complicates the issue of how hydrogen use may be expanded and necessitates careful forethought as key technology paths unfold. We must remember that the additional cost and complexity of building a hydrogen infrastructure is only justified if significant benefits to society are in fact likely to accrue.

This paper has been written for two primary purposes. First, we argue that the time is ripe for an expanded science and technology initiative in California for clean energy development and greater end-use energy efficiency. This initiative should span transportation systems, electrical power generation, and natural gas and other fuel use, and should place the potential for expanded use of hydrogen within this broader context. Second, we specifically discuss potential concepts and strategies that California might employ as it continues to explore the use of hydrogen in transportation and stationary settings. The authors believe that at this stage the question is not *if* California should continue with efforts to expand hydrogen use, because these efforts are already underway, but *how* these efforts should be structured given the level of effort that ultimately emerges through various political and corporate strategy processes. However, we feel that it is critical that these efforts take place in the context of a broader "no regrets" clean energy strategy for California.

Opportunities and Obstacles for Hydrogen

We also feel that it is important to point out that the potential use of hydrogen confronts serious remaining obstacles. These obstacles and barriers have recently been well articulated as part of a major review effort on behalf of the National Academy of Sciences / National Research Council. However, we note that hydrogen is one of very few options for significantly reducing oil use and greenhouse gas emissions in the transport sector. Hydrogen has an unmatched potential (based on present knowledge) as part of a set of solutions to a variety of energy and environmental problems. Hydrogen can be produced from a wide range of potential feedstocks within the U.S. and most other countries, potentially improving the balance of trade and geopolitical concerns associated with heavy oil dependence in the transportation sector. In fact, we suggest that it is *the* most compelling option for a low-carbon, post-petroleum future at this time.

A principal attraction of hydrogen is the ability to produce it from a variety of sources, including renewable sources. Hydrogen can be produced from wind and solar power and various biomass and waste resources – as well as from coal, natural gas, and nuclear power. With regard to fossil sources, carbon sequestration offers a potential future (but for the most part presently unproven) concept for production with low greenhouse gases (GHG) emissions to the atmosphere. Hydrogen technologies such as fuel cells, along with other small-scale power generating systems, are also promising for "distributed power generation" (DG). DG can allow production of electricity for commercial and residential buildings and industrial facilities with reduced needs for electricity transmission and distribution. Total energy efficiency levels from

DG can exceed those of central power plants, especially when waste heat is used for "cogeneration" or "combined heat and power" (CHP). Most importantly, hydrogen can be produced and used in ways that significantly reduce or even eliminate emissions of GHGs and air pollutants.

In light of this potential promise, there is a need to prepare for the potential transition to hydrogen since the process will be slow and initially difficult. There is much to learn about the use of hydrogen, the adoption of appropriate codes and standards, and the issues and obstacles associated with public acceptance of its use. Our concern here is different, however, and we believe more urgent and compelling. It is the need to rapidly advance the science and engineering of renewable energy and hydrogen technologies. We believe that the "hydrogen economy" is ultimately likely to come about, but we also conclude, along with the National Research Council and many others, that significant scientific and engineering advances are needed for the transition to advance in a meaningful and sustainable fashion.

Principles and Strategies for Clean Energy Policy

Furthermore, a major science and technology effort is needed more broadly to spur clean energy system development. This is necessary both in order for the potential hydrogen economy to deliver the benefits that are possible, and also in case the "great hydrogen experiment" is not successful. With its strong energy science and technology foundation, California is uniquely positioned to take a leadership role in this regard both within the U.S. and globally. We recommend a strategy that:

1) Advances the production of renewable electricity based on wind power, solar PV, and biomass;
2) Emphasizes *more efficient use of energy* with development and deployment of more efficient heating, ventilating, and air conditioning systems, lighting systems, appliances, and commercial/industrial equipment, and with introduction of higher fuel economy light and heavy-duty vehicles;
3) Expands clean and efficient distributed power generation (DG) through the use of combined heat and power (CHP) systems and "smart grids" -- and explores the use of stationary fuel cells and other hydrogen-based DG technologies in this context;
4) Continues and expands partnerships among U.S. DOE, industry, and the universities and labs to address key renewable energy, fuel cell, and hydrogen storage and delivery technology research and development (R&D); and
5) Explores renewable hydrogen production along with additional means of clean hydrogen production based on "transition fuels" such as natural gas and coal (including efforts to experiment with carbon sequestration), but that "holds the bar high" with regard to their full fuel-cycle environmental performance.

We further recommend that this strategy be pursued by efforts to coordinate and align various State energy R&D and financing mechanisms for clean energy system development, to aggressively pursue federal clean energy R&D funds, and to explore additional funding mechanisms. The major State mechanisms include the $64 million per year California Energy Commission (CEC) Public Interest Energy Research program, financing available under the California Alternative Energy and Advanced Transportation Financing Authority, the $200 million "Green Wave" clean energy investment program developed by State Treasurer Angelides, a re-aligned and expanded natural gas system public purpose R&D program, continued efforts to garner federal energy and transportation R&D and demonstration project funds, and a new $16 million clean technology incubator sponsored by Pacific Gas and Electric, among other mechanisms.

The California Policy Setting and Energy and Environmental Conditions

The fact is that many U.S. states and nations around the world are aggressively positioning themselves to compete with California's role in this regard. The issues involved are therefore not only related to environmental and energy concerns, but also to local and regional economic development and to which states and countries will develop the most effective clusters for clean energy and transportation industrial activity.

California is a unique setting for clean energy technology development for several reasons. If considered a nation-state of its own, California would represent the fifth largest economy in the world. It is home to some 34 million people who drive 23 million automobiles. The State has historically experienced significant air quality problems and has special status under the Clean Air Act to enact its own particular air quality control measures. California is a global leader in high technology research and development, environmental policy and regulation, and agricultural and forestry production. It also is a major entertainment center and "style leader" for the U.S. and the world.

With regard to clean energy and alternative fuels for transportation, California has also taken a leading role. The State derives approximately 11 percent of its electricity from renewable sources, with plans to increase the percentage to 20 percent by no later than 2017. California has experimented with various alternative transportation fuels over the years and has aggressive plans to curb air pollution and greenhouse gases under the "zero emission vehicle mandate" and the "Pavley Law." California has more than one-fourth of the hybrid electric vehicles in the U.S. (over 11,000 at the end of 2003), and it is home to the California Fuel Cell Partnership – a public/private consortium that has tested 55 fuel cell powered vehicles in California over more than 145,000 accumulated miles – and the California Stationary Fuel Cell Collaborative that is promoting the commercialization of stationary fuel cell technologies.

More recently, California Gov. Schwarzenegger announced his intent to create a "California Hydrogen Highway Network" by signing executive order S-7-04 on April 20th, 2004. This initiative is intended to stimulate development of hydrogen infrastructure in California to remove a key barrier to the introduction of hydrogen-powered vehicles. Among other measures, this order designates the 21 interstate highways as part of that network and calls for a "California Hydrogen Economy Blueprint Plan" to be developed by January 1, 2005 for the "rapid transition to a hydrogen economy in California."

Key Elements of a California Hydrogen Strategy

As California expands hydrogen R&D, demonstration and experimentation projects, and infrastructure planning activities, we advocate a strategy that integrates the potential use of hydrogen into additional energy sectors beyond transportation systems. Future use of hydrogen in the transportation sector appears to have the greatest potential among known options for large reductions in GHGs, air pollutants, and petroleum use, but the barriers to hydrogen and fuel cell use for transportation remain significant. The use of hydrogen technologies for DG may become commercially attractive well before transportation, and there are also interesting potential synergies between the two. Furthermore, the combination of hydrogen systems with other advanced transportation technologies and concepts may also yield important synergies and efficiencies.

We recommend a strategy that includes the following key elements:

1) Build on existing projects, programs, and energy and transportation infrastructure and pursue aggressive but incremental steps as the vehicle market develops;
2) Use public/private partnerships to leverage resources and combine expertise;
3) Explore the integration of hydrogen infrastructure development with distributed electrical power generation (e.g. hydrogen “energy stations”) and innovative mobility systems (e.g., shared-use vehicle services facilitated by electronic and wireless reservation and communication technologies);
4) Focus initial hydrogen infrastructure developments on prioritized “key corridors” and in a coordinated fashion, and include experimentation with innovative low-cost hydrogen distribution options (e.g. mobile dispensing platforms and integration with activities with large fleet and retail companies);
5) Emphasize and lay out a clear plan for using California’s domestic resources to produce hydrogen cleanly, and increasingly from renewable sources, and prioritize R&D on electrolyzer and biomass-to-hydrogen systems;
6) Experiment with hydrogen for off-road uses including forklifts and other vehicles operating inside buildings, construction site applications, and in maritime and agricultural settings;
7) Demonstrate hydrogen safety and reliability through development of codes and standards and documentation of safety performance for hydrogen energy systems;
8) Use State action to encourage all hydrogen refueling stations, including those owned by public and private fleets, to be available to the public (wherever practical); and
9) Employ existing and new mechanisms, such as the partnership among Caltrans, the Air Resources Board, and CEC, to coordinate State agency activities as appropriate.

These measures among others can help to maximize the effectiveness of efforts to pursue the expanded use of hydrogen, reduce the risks of misplaced investments and stranded assets, and help to advance broader economic, environmental performance, and mobility goals.

Conclusions

We make the above recommendations for California hydrogen policy in the context of a major science and technology initiative aimed at making California a global leader in clean energy. We also more generally recommend greater R&D and clean technology market development support for the energy sector due to its seemingly ever greater importance in geopolitics, environmental health and justice, and social health and well being.

Hydrogen investments should constitute one part of a balanced energy R&D and development portfolio that also emphasizes more “tried and true” energy efficiency and clean fuel solutions. This will require strengthened and coordinated policies for development of renewable and other clean energy sources, continued and enhanced policies for cleaner and more efficient light and heavy-duty vehicles, greater attention to improving energy end-use efficiency, and leveraged and coordinated financing and R&D funding strategies.

In conclusion, continued development and deployment of clean energy technologies is critical to California's future economic growth, human health and welfare, and environmental quality. Hydrogen technologies represent one important part of this future, but *it is essential that efforts to promote hydrogen as an energy carrier occur in the context of a broader clean energy and energy efficiency strategy for the State*. This strategy would enhance the benefits that hydrogen can offer if the "hydrogen economy" does in fact develop rapidly, but it also would provide clear benefits to the State even if it does not.

"All technology should be assumed guilty until proven innocent."

- David Brower

"Ever bigger machines, entailing ever bigger concentrations of economic power and exerting ever greater violence against the environment, do not represent progress: they are a denial of wisdom. Wisdom demands a new orientation of science and technology towards the organic, the gentle, the non-violent, the elegant and beautiful."

- E.F. Schumacher

"It will take a combined effort of academia, government, and industry to bring about the change from a gasoline economy to a hydrogen economy. The forces are building and progress is being made. It is of major importance that a change of this magnitude not be forced on unwilling participants, but that all of us work together for an economically viable path to change."

- Dr. Geoffrey Ballard

Introduction: California's Role in the Development of the Hydrogen Economy

Hydrogen is rapidly gaining interest as a potential energy carrier for transportation and stationary power applications. This interest is due to the potential that hydrogen has as part of a set of solutions to a variety of energy and environmental problems -- and based on this potential the current high level of interest in the use of hydrogen is understandable. In our view, however, full realization of the benefits that hydrogen can offer will not be possible without a clear strategy for producing hydrogen from clean and sustainable sources. One of hydrogen's greatest benefits – having a wide range of potential feedstocks for its production – also complicates the issue of how hydrogen use may be expanded and necessitates careful forethought as key technology paths unfold. The additional cost and complexity of building a hydrogen infrastructure is only justified if significant benefits to society are likely to accrue.

This paper has been written for two primary purposes. First, we argue that the time is ripe for an expanded science and technology initiative in California for clean energy development and energy efficiency more generally, which spans both transportation and electrical power generation and within which the potential use of hydrogen as an energy carrier should be explored. Second, we specifically discuss potential concepts and strategies that California might employ as it continues to explore the use of hydrogen in transportation and stationary settings. The authors believe that at this stage the question is not *if* California should continue with efforts to explore the use of hydrogen, because in fact these efforts are already underway, but *how* these efforts should be structured given the level of effort that ultimately emerges through various political and corporate strategy processes. However, we feel that it is critical that these efforts take place in the context of a broader "no regrets" clean energy strategy for California.

We also feel that it is important to point out that the potential use of hydrogen confronts serious remaining obstacles, as we discuss below. These obstacles and barriers have recently been well articulated as part of a major review effort on behalf of the National Academy of Sciences (NAS) and the National Research Council (NRC) (NAS/NRC, 2004). However, we note that hydrogen also has unmatched potential (based on present knowledge) as part of a set of solutions to a variety of energy and environmental problems. Hydrogen can be produced from a wide range of potential feedstocks within the U.S. and most other countries, potentially improving balance of trade and geopolitical concerns associated with heavy dependence on oil in the transportation sector. In particular, hydrogen can be produced from wind and solar power, biomass sources, and other sustainable processes – thereby providing a series of potential linkages between renewable energy and transportation fuels.

Hydrogen technologies such as fuel cells, along with other small-scale power generating systems, are also promising for "distributed generation" (DG) of electrical power. DG can allow production of electricity for commercial and residential buildings and industrial facilities with reduced needs for electricity transmission and distribution. Total energy efficiency levels from DG can exceed those of central power plants, especially when waste heat is used for "cogeneration" or "combined heat and power" (CHP). Perhaps most importantly, hydrogen can be produced in ways that significantly reduce or even eliminate emissions of greenhouse gases (GHGs) and air pollutants. We are aware of no other set of potential energy pathways that offer this complete set of potential benefits, within the timeframe possible for deployment of renewable/hydrogen-based energy and transportation technologies.

We thus believe that the fundamental question for hydrogen system R&D and deployments is not the question of: "*How should hydrogen be funded versus funding for other options?*" Rather, the appropriate question is: "*How should hydrogen technology and other longer-term investments be balanced with other investments so that a complete portfolio of options is being pursued?*" In this way, first niches and then perhaps eventually a larger role for hydrogen can be identified along the course of a "no regrets" policy that focuses primarily on energy efficiency and clean electricity production. The portfolio of investment options includes the following broad categories:

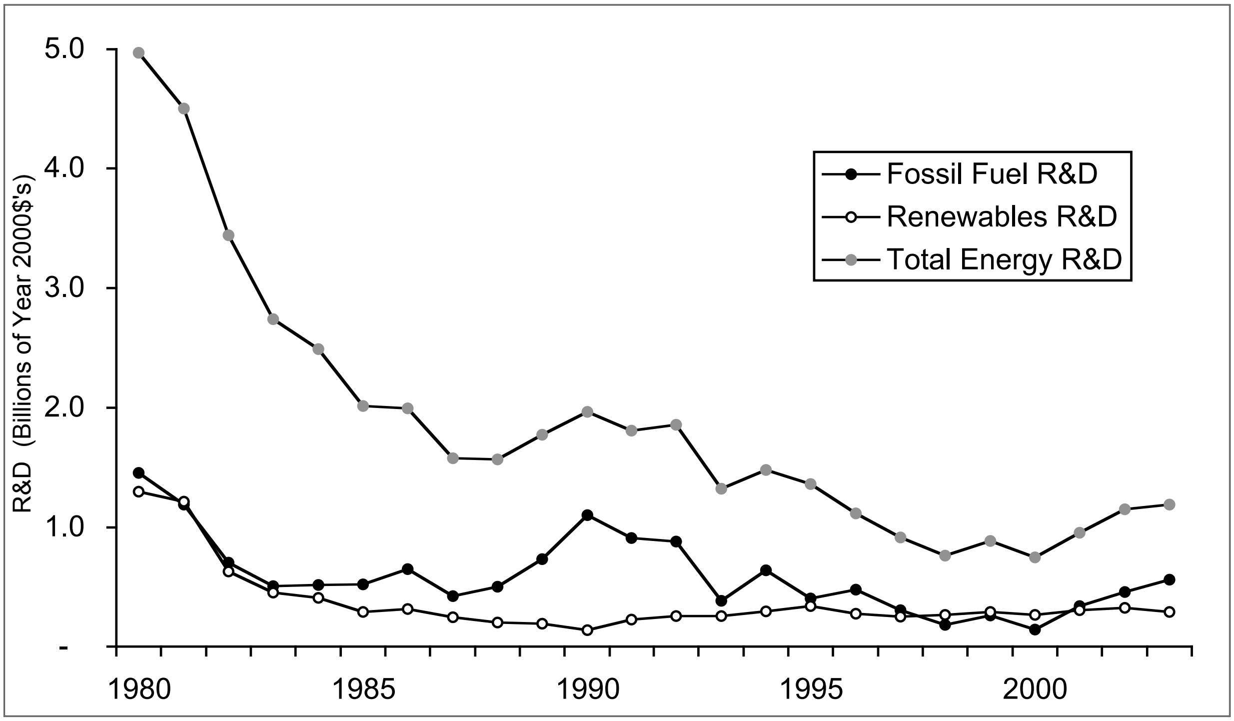
1) Strategies that offer clear environmental and social benefits and either are already or are becoming commercially competitive, such as energy efficiency measures, wind power, solar PV, hybrid-electric cars, and biomass (and we recommend emphasizing these);
2) Near-term incremental steps that are more proven but appear to be inherently limited in one or more important ways with regard to their overall environmental and energy security benefits (such as advanced conventional vehicles and improved fossil-fuel based power generation); and
3) "Chancier" technological propositions that offer greater long-term potential and that appear to have the requisites for ultimate cost-effectiveness and consumer acceptance (such as fuel cell/electrolyzer technologies and the expanded use of hydrogen).

We have a strong overall belief that energy sector R&D is under-funded in the U.S., and that the time is right for California to undertake a major science and technology initiative that emphasizes renewable energy, hydrogen as an energy carrier, and fuel cell and electrolyzer technologies. In fact, we feel that R&D efforts should be expanded in several key areas in the energy sector. These areas include most notably renewable energy systems and biofuels, electrical grid infrastructure and distributed power generation for “smart grids,” energy efficiency and demand response technologies, innovative transportation and “transportation substitution” technologies, and transitional low-emission, fossil-fuel based systems.

We also need to focus more attention on the root causes of our consumptive patterns of energy use. These efforts will include greater focus on energy end-use efficiency (with whatever fuel/energy carrier is being used), attention to urban planning to revitalize downtown areas and make them more desirable and “livable,” and better inter-modal travel opportunities so that public transit, bicycling, and walking become more efficient, safe, and practical. Such efforts would be complementary with improvements in systems for energy production and use, and would help to provide compounded benefits.

As shown in Figure 1, below, overall federal funding for energy R&D has declined from about $5 billion in 1980 to less than $2 billion per year throughout the 1990s (in constant Year 2000 $s). Renewable energy funding has been flat at about $300 million per year for more than a decade, while fossil fuel energy R&D has increased significantly under the Bush Administration from $140 million in 2000 to $560 million in 2003. Fossil fuel R&D spending increases represent nearly all of the increase shown in Figure 1 in total U.S. energy R&D spending seen since energy research funding levels “bottomed out” in the late 1990s. We further note that only about 1% of gross annual sales are spent on energy R&D in the U.S., compared with levels of about 5% for industrial chemicals, 6% for transportation equipment, and 10% for communications equipment and drugs and medicine (Margolis and Kammen, 1999). Our energy system is simply too vital to our economy and to our social well being to receive such minimal investments in future progress.

Figure 1: U.S. Federal Energy R&D Spending Trends



Source: Nemet and Kammen, 2004 (forthcoming)

Hydrogen-Related Developments in California and the Need for a Major Science and Technology Initiative

Irrespective of the broader energy policy and hydrogen energy debate, the level of interest and involvement in hydrogen in California is clearly expanding. Notable recent developments include the "California Hydrogen Highway Network" Executive Order (S-7-04) signed by Gov. Schwarzenegger on April 20, 2004 at the University of California (UC) Davis, and the strong hydrogen focus of the U.S. Department of Energy (DOE) over the past few years.

In a major announcement on April 26, 2004, DOE Secretary Spencer Abraham confirmed that a total of $350 million in hydrogen infrastructure funding would be made available from DOE over five years, in four major new program areas. These program areas are "Hydrogen Storage," "Vehicle Infrastructure and Learning Demonstrations," "Fuel Cell Research," and "Hydrogen Education." California is well positioned to benefit from these new programs, with its current strong position in the hydrogen/fuel cell arena and with several world-class research centers at its universities and national labs. We estimate that as much as $75-100 million of this funding will be applied to research, development, demonstration, and public education programs within the State over the next five years, depending on the actual levels of funding that are appropriated by Congress.

Thus, with its strong science and technology foundation and several important policy-related factors discussed below, California is uniquely positioned to play a leading role in the expanded use of clean energy technologies and what may prove to be "the next industrial revolution." The fact is that many U.S. states and nations around the world are aggressively positioning themselves to compete with California's role in this regard. The issues involved are therefore not only related to environmental and energy concerns, but also to local and regional economic development.

The fundamental thrust behind this paper is to call for a major science and technology initiative in California to promote clean energy technology development and deployment, and to also suggest promising concepts for pursuing hydrogen infrastructure developments within this context and in an integrated fashion with other clean energy and advanced transportation systems. The barriers to the use of hydrogen, though significant at present to be sure, are all in principle solvable in our view. Furthermore, California is one of the best if not the best area of the world to work on them.

We acknowledge the possibility that the remaining issues associated with the use of hydrogen may or may not ultimately be solved. There is no sure way of knowing at this time. However, we believe that when examined from a broader social perspective, the environmental and energy problems that could be addressed through the use of hydrogen in the context of renewable energy-based hydrogen solutions -- coupled with the lack of other compelling medium and long-term options for solving these problems -- warrants at least the present level of continued effort.

We recommend a clean energy strategy for California that:

1) Advances the production of renewable electricity based on wind power, solar PV, and biomass;
2) Emphasizes *more efficient use of energy* with development and deployment of more efficient heating, ventilating, and air conditioning systems, lighting systems,

appliances, and commercial/industrial equipment, and with introduction of higher fuel economy light and heavy-duty vehicles;

3) Expands clean and efficient distributed power generation (DG) through the use of combined heat and power (CHP) systems and “smart grids” -- and explores the use of stationary fuel cells and other hydrogen-based DG technologies in this context;
4) Continues and expands partnerships among U.S. DOE, industry, and the universities and labs to address key renewable energy, fuel cell, and hydrogen storage and delivery technology R&D; and
5) Explores renewable hydrogen production along with additional means of clean hydrogen production based on “transition fuels” such as natural gas and coal (including efforts to experiment with carbon sequestration), but that “holds the bar high” with regard to their full fuel-cycle environmental performance.

We further recommend that this strategy be pursued by efforts to coordinate and align various State energy R&D and financing mechanisms for clean energy systems development, to aggressively pursue federal clean energy R&D funds, and to explore additional funding mechanisms. The major State mechanisms include the $64 million per year CEC Public Interest Energy Research (PIER) program, financing available under the California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA), the $200 million “Green Wave” clean energy investment program developed by State Treasurer Angelides, a re-aligned and expanded natural gas system public purpose R&D program, continued efforts to garner federal energy and transportation R&D and demonstration project funds, and a new $16 million clean technology incubator sponsored by Pacific Gas and Electric (PG&E), among other mechanisms.

This paper next discusses the energy and environmental policy setting in California, followed by a brief description of the present status of hydrogen infrastructure in the State, and key remaining barriers for the use of hydrogen in the transportation sector. The authors then make several recommendations for developing hydrogen systems in California in an integrated manner for both transportation and stationary power, along with further discussion of potential financing mechanisms for both clean energy and hydrogen systems R&D and deployment.

The California Context: Energy and Environmental Conditions in the State

California produces a gross state product of approximately $1.4 trillion annually, or over 13% of the gross domestic product (GDP) of the U.S. (U.S. BEA, 2003). In fact, if considered to be a country of its own, California would represent the fifth largest economy in the world ranking above France, Italy, and China (EIA, 2003). It is home to over 34 million people who operate more than 23 million automobiles (U.S. Census Bureau, 2003; Caltrans, 2000).

California has historically experienced significant air quality problems, with approximately 24 million people in 27 counties living in areas out of attainment with federal ozone standards, and nearly 19 million people in 15 counties living in areas out of attainment with federal particulate matter standards (U.S. EPA, 2001). Because of these problems, California has special status under the Clean Air Act to enact its own special air quality control measures. Furthermore, California contributes approximately 6% to the total annual anthropogenic GHG emissions of the U.S. (U.S. EPA, 2001).

More generally, California is a global leader in high technology research and development, environmental policy and regulation, and agricultural and forestry research and production. Much of the world "looks to" California for technological developments, cinematic, television, and musical entertainment. For these reasons among others, California has become a leader with regard to alternative fuels for transportation and clean energy technologies for electricity production.

During the 1980s and 1990s, the State experimented with a variety of transportation fuels including natural gas, propane, diesel and biodiesel, and electricity. Most recently, hybrid gasoline-electric vehicles (HEVs) have received a popular consumer response to their initial introduction. In 2003, 43,435 HEVs were registered in the U.S. -- up 26% from 2002 -- and California ranked first among states with 11,425 of these registrations (Road and Track, 2004). Efforts are also underway to explore the use of hydrogen as a transportation fuel, and the California Fuel Cell Partnership (CAFCP) -- inaugurated by the California Air Resources Board along with many industry and governmental partners in 1999 – has successfully and with global attention been testing hydrogen-powered fuel cell vehicles for the past five years. Since 2000, the CAFCP has placed 55 light-duty FCVs in California, and these vehicles have been driven more than 145,000 miles (CAFCP, 2004).

In the stationary power sector, California is also on the leading edge. California currently derives approximately 11% of its electrical energy from renewable energy feedstocks[1] (CEC, 2003a). It has established a "renewable portfolio standard" (RPS) to increase this percentage to 20% by 2017, and also is promoting high-efficiency advanced power generating systems based on combined heat and power (CHP) – also known as "cogeneration" – and stationary fuel cells. The California Energy Commission (CEC) administers the PIER program, which uses funds collected through an electricity "public goods charge" to provide approximately $60 million per year for R&D on renewable, clean, and efficient technologies for electricity generation and use. The State also has the California Stationary Fuel Cell Collaborative (CASFCC) – a public/private sector collaboration to promote the deployment of stationary fuel cell systems.

California attempted to deregulate its electricity market in the late 1990s based on the passage of AB 1890 in 1996. The experiment failed spectacularly, however, when in 2000 the deregulated market design allowed wholesale prices to rise dramatically before they could be controlled again with emergency measures to re-regulate the industry. Appendix I of this paper provides a brief synopsis of this electricity market deregulation experience.

California's Automobile Industry

While Detroit, Michigan is the recognized center of the U.S. automobile industry, California has significant leadership in the automotive sector. California is an automobile design center, with nearly every major global automaker having design and/or research and development facilities located in the State. Furthermore, California's New United Motor Manufacturing Inc. (NUMMI) plant in Fremont – a joint venture between Toyota and General Motors – produces over 350,000 vehicles annually for Toyota and Pontiac (Automotive Intelligence, 2004).

With California's position an environmental policy and transportation technology leader, and the energy and environmental quality issues confronting the State, California is well positioned to expand its role in the automobile industry of the 21st century. The highly successful introduction of HEVs, along with the presence of key policy drivers (including the ZEV mandate and the Pavley Law -- discussed below) suggest that California will continue to lead the development of

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[1] See below for more details on the California electricity generation mix.

clean fuel vehicle technologies.

However, additional policy and regulatory measures, such as demand side measures to complement the activities to research and develop clean vehicle technologies, could help to solidify and further these opportunities. Specific policy measures that could aid in promoting California's clean fuel vehicle industry are discussed in Section 4 of this paper, in the context of hydrogen and other clean fuel vehicle development efforts.

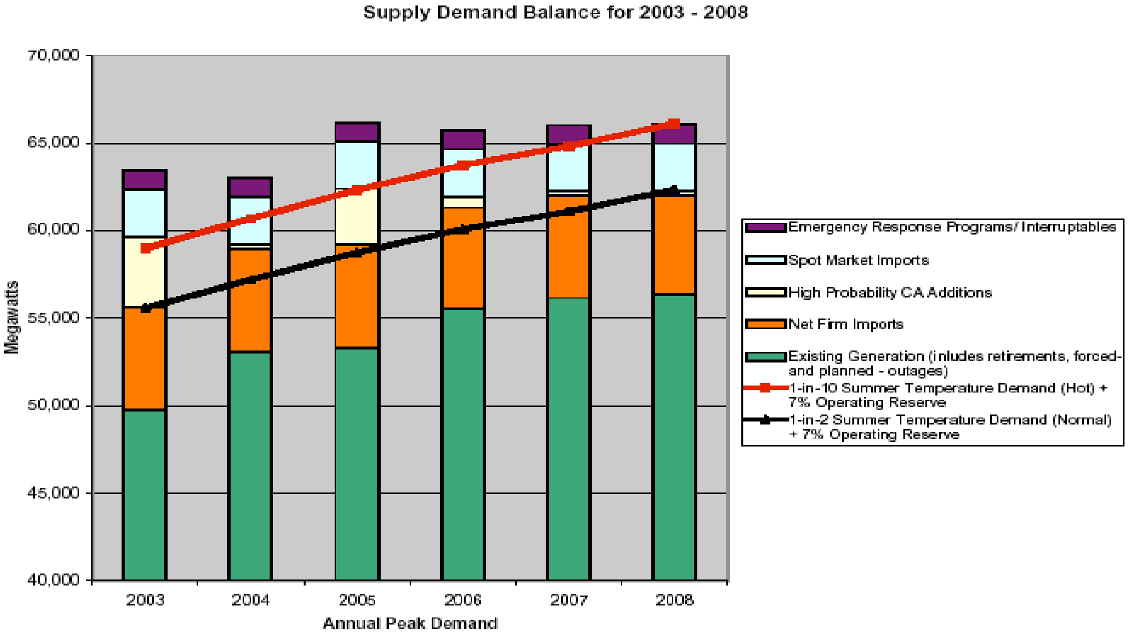
California's Electricity and Energy Market Situation

California is for the most part self-sufficient with regard to gasoline and electricity production, but significant amounts of electricity are imported from the Pacific Northwest during the summer months and from power plants in other nearby states year-round. California's 22 major oil refineries produce 46 to 50 million gallons of gasoline each day, compared with a usage level of about 42 million gallons, meaning that approximately 10% of production is exported to nearby states including Arizona and Nevada (CEC, 2003b). Approximately 80% of California's electrical energy is produced within the State with about 20% imported, with some annual variation depending on weather conditions, hydropower capacity in the Northwest, and other variables (CEC, 2003c).

In contrast, California's natural gas usage is based predominantly on imports from other states and from Canada. In 1999, California produced about 16% of the natural gas used in the state, with 46% coming from the Southwest, 28% from Canada, and 10% from the Rocky Mountain region (CEC, 2001). With the current heavy emphasis on natural gas as a feedstock for the expansion of electrical power production capacity, this reliance on out-of-state resources is of increasing concern. The 1999 California domestic natural gas output of about 6 billion cubic feet of gas was 40% below 1985 production and, while increased drilling activity in Northern California is likely to lead to increased production in the future, production is not expected to return to 1985 levels at any time during the next 20 years (CEC, 2001).

With regard to current sources of supply for electricity, California currently relies on natural gas for the generation of about 36% of its power, coal for 20%, large hydro for 18%, nuclear for 15%, geothermal for 5%, and solar, wind, small hydro and other renewable sources for about 6% (CEC, 2003a). The state has a legislated renewable energy procurement standard or "RPS" (Senate Bill 1078 passed in 2002) that calls for investor-owned utilities to steadily increase the amount of renewable energy that they purchase. The increase required by the RPS law is from the present level of about 11% to a full 20% by 2017. However, in its last Integrated Energy Policy Report the CEC has recommended accelerating this goal to achieve the 20% renewables level by 2010 (CEC, 2003e). Gov. Schwarzenegger has publicly supported this accelerated RPS goal, and has further indicated support for a 33% RPS for 2020. Figure 3 shows that the State's electricity supply is expected to tighten somewhat in the coming years despite increases in generating capacity, due to steady increases in forecast demand.

Figure 3: Five-Year California Electricity Supply Forecast



Source: CEC, 2003d

Environmental Concerns and Key Policy Measures in California

As noted above, California has historically been a leader within the U.S. with regard to the development of important environmental policies and regulations. In the original Clean Air Act of 1970, California was granted the ability to promulgate different air quality regulations than the rest of the country due to its particularly severe air quality issues. California has also been particularly active with regard to soil and water contamination – both in terms of prevention and remediation – as well as coastal protection.

One important example of California's leadership in the air quality area is in its regulation of mobile sources and the Low-Emission Vehicle (LEV) regulations that have been developed by the California Air Resources Board (ARB). These regulations have required strict control of tailpipe emissions from on-road motor vehicles, and a well-publicized and hotly debated provision of the regulation – known as the zero-emission vehicle (ZEV) mandate – requires the introduction of vehicles that produce no tailpipe emissions at all. The provisions of the ZEV mandate have been significantly altered over the years through successive bi-annual review proceedings, and emphasis has broadly shifted from battery electric vehicles (BEVs) to HEVs and fuel cell vehicles (FCVs).

In its most recent incarnation, the ZEV mandate has a two-pronged character with regard to its most stringent category of clean vehicles that requires either significant numbers of ZEVs based on battery technology, coupled with sales of other clean vehicles, or a much smaller number of hydrogen-fueled FCVs coupled with a large component of advanced-technology "partial" ZEVs (AT-PZEVs). Most of the automakers bound by the provisions of the ZEV mandate appear to be favoring the latter path, but actual compliance strategies are unclear at this point. These "gold standard" ZEV and AT-PZEV vehicles would be complemented by additional "silver standard" AT-PZEVs to equal 4% of vehicles "delivered for sale" by major manufacturers. An additional 6% of vehicles delivered would be "bronze standard" PZEVs that could be conventional vehicles with advanced emission control systems. The “gold” and “silver” category percentages slowly increase through 2018, with the total percentage for all categories increasing from 10% initially in 2005 to 11% in 2009, 12% in 2012, 14% in 2015, and 16% in 2017 (ARB, 2003).

In support of the ZEV mandate goal to introduce ZEVs and other clean vehicles in California, Gov. Schwarzenegger recently announced his intent to create a “California Hydrogen Highway Network” by signing executive order S-7-04 on April 20th, 2004. This initiative is intended to stimulate development of hydrogen infrastructure in California to remove a key barrier to the introduction of hydrogen-powered vehicles. Among other measures, this order designates the 21 interstate highways as part of that network and calls for a “California Hydrogen Economy Blueprint Plan” to be developed by January 1, 2005 for the “rapid transition to a hydrogen economy in California.” This executive order is discussed in more detail in Section 4 below.

Another important policy driver in California is AB 1493, which became known as the “Pavley Bill” after its initial introduction by primary sponsor Fran Pavley (D-41st District). This law requires California to develop measures to restrict GHG emissions from the light-duty motor vehicle sector. Under the law, ARB must develop a regulation that requires automakers to reduce global warming emissions from non-commercial passenger vehicles “to the maximum feasible and cost-effective extent” starting with the 2009 model year.

The Pavley Law is particularly noteworthy in light of the fact that the U.S. as a whole has not ratified the “Kyoto Protocol” established by the United Nations Framework Convention on Climate Change (UNFCCC) at its Conference of the Parties (COP) meeting in Kyoto, Japan in 1997.[2] A revised version of the Kyoto Protocol has now been ratified by 120 nations that together account for more than 44% of global emissions, but in comparison the U.S. alone produces over 36% of global emissions (UNFCCC, 2003). This means that over 80% of global emissions would be included under the treaty if the U.S. were to sign on, and over 97% of emissions would be included if the Russian Federation were also to join.

California has established the California Climate Action Registry program – a voluntary registry for early action on climate change -- and has just started to work with other western states on the climate change issue through the Western Governors Association. In September of 2003, a group of Governors including California’s Gray Davis, Washington’s Gary Locke, and Oregon’s Ted Kulongoski accused the Bush Administration of moving too slowly on the climate change issue and vowed that “if Washington, D.C., will not lead, then the West Coast of the United States will lead on global warming” (Associated Press, 2003). The group of governors has launched a new “tri-state” initiative to examine the potential for additional state actions on the greenhouse gas emissions issue, including the use of combined buying power to obtain fuel-efficient vehicles, reduction of diesel fuel emissions from ships and trucks, promotion of more renewable energy, development of uniform efficiency standards, and better measurement and reporting of greenhouse gas emissions and climate change (Associated Press, 2003).

The fact that other states appear to have been emboldened by California’s action’s related to GHG emissions again highlights the potential added value of California leadership in environmental policy, and the ability of the states to advance policy in concert with, and at times in advance of, policy action at the federal level.

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[2] The initial Kyoto Protocol was further developed at COP4 in Buenos Aires in 1998 and at COP6 in The Hague in 2000, and has reached a stage of culmination with the adoption of “The Marrakesh Accords” at COP7 in 2001 (UNFCCC, 2003).

Hydrogen as a Fuel for Transportation and Distributed Power Generation

In recent years, and particularly since early 2003 after being emphasized at the national level by the Bush Administration, the prospect of introducing hydrogen as a transportation fuel has gained great attention. Compared with the gasoline and diesel fuel that dominate in the U.S. transportation sector, hydrogen offers several significant potential advantages. First, hydrogen is in reality an "energy carrier" and not a primary fuel, and as such it can be produced from a wide range of potential feedstocks. Unlike gasoline, where domestic production is on the decline and imports are on the rise, hydrogen can be produced in many different ways and with resources that are abundant in California and throughout the U.S. These resources include biomass, natural gas, landfill gas, oil, and coal, as well as the wide range of additional resources that can be used to produce electricity.[3] Second, hydrogen can be combusted cleanly with minimal air pollutant emissions and can be used in fuel cells to produce electrical energy with no emissions at all, except of water vapor. When used in FCVs, hydrogen affords the opportunity of avoiding two key disadvantages of BEVs – short driving range and long refueling time – while providing many of the same private and public benefits.

Most attention on hydrogen is being focused on its use as a transportation fuel – either with FCVs or with hydrogen combustion vehicles – but hydrogen also offers opportunities for clean electricity production through "distributed generation" (DG). Under this concept, electrical power would be produced not through large power plants that typically transmit power relatively long distances, but rather through onsite generation that would produce power for local uses.

This DG concept would reduce the need for and efficiency losses associated with electrical power transmission and distribution, and can offer the prospect of increased efficiency particularly when waste heat from electricity production is used productively for combined heat and power (CHP) or "cogeneration." When this waste heat is used – either for heating or cooling needs of buildings or industrial processes – the overall thermal efficiency of DG systems can easily reach 80 to 85% (with levels of up to about 97% theoretically possible), far besting the most advanced large-scale power plants where waste heat recovery is impractical.

Competition with Other States for Hydrogen and Fuel Cell Industry Development

In addition to worldwide competition in the global technology and energy economy, there also is competition within the U.S. in the race for hydrogen and fuel cell system development. States such as Connecticut, Michigan, Ohio, New York, and Texas are enacting bold initiatives such as "NextEnergy" in Michigan, "Fuel Cells Texas," and the "Ohio Fuel Cell Coalition" to garner private sector and federal investment for the development of these industries. With significant federal funding now being allocated for hydrogen and other clean energy system development, and with venture capital markets taking large positions in the clean energy sector, California stands to lose much if it does not compete for these resources.

As we suggest throughout this paper, however, California does at present have a strong position in this arena. California represents a combined high technology and financial center that few other states can match, including a strong presence in energy/environmental technologies. Some analysts have noted that the potential exists for a new "industrial revolution" to center around clean energy technologies and other green products (Lovins et al., 1999; Moore and Miller, 1994), and California is well positioned to reap the benefits of this revolution. The State is already home to the CAFCP, currently testing about 30 hydrogen fuel cell cars and buses and with over 145,000 miles of combined FCV operation by the end of 2003

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[3] The two primary means of producing hydrogen are either by "reforming" a hydrogen rich liquid or solid fuel that contains hydrogen, or by generating it from water and electricity through the process of electrolysis.

(CAFCP, 2004). California also has the CASFCC,[4] as well as the California Hydrogen Business Council,[5] and it has a strong fuel cell and hydrogen industry presence. With continued effort and positioning, California could become even more of a national leader in the pursuit of the hydrogen economy. However, in this competitive environment there may be an important role for alliances with nearby states to help to leverage resources and more effectively garner shares of federal R&D funds, a point that we discuss further below.

2. Issues and Obstacles for the Development and Deployment of Hydrogen Infrastructure, Vehicles, and Power Systems

The development of hydrogen-refueling infrastructure in California will be a significant and costly undertaking, and one that entails potential pitfalls. The risks associated with investing in refueling infrastructure in advance of a widespread vehicle introduction include the potential for assets to be stranded if the vehicle uptake and fuel demand growth is delayed, and for other conditions to change in ways that undermine the use of hydrogen for transportation and other uses. These might include increases in natural gas prices, with natural gas needed as a key interim fuel as other sources of hydrogen are developed, slow progress in improving the performance of onboard hydrogen storage systems, and the lack of strong policy drivers to support the introduction of hydrogen-powered vehicles (should for example the ZEV mandate become weakened in subsequent revisions).

These challenges are balanced by the potential “upside” of successful hydrogen introduction, but we feel that it is critical to point out that these challenges are real and should not be overlooked. The recent report by the NAS/NRC highlights the key issues facing the use of hydrogen for transportation and other uses. These issues include the low energy density of onboard hydrogen storage, high fuel cell system costs, relatively low proven durability of some fuel cell technologies, the costs of hydrogen distribution when produced in large centralized plants, and the relatively high costs and low technical maturity of low-carbon hydrogen production systems (NAS/NRC, 2004).

However, California has become a major hub of development for the renewable energy, hydrogen, fuel cell, and advanced transportation technology industries and is therefore well positioned to lead the nation and the world in conducting research to solve these problems. Appendix II of this paper presents a list of the many hydrogen and fuel cell companies and research organizations within California, with nearly 100 organizations identified.[6]

Key Features of Hydrogen Technologies

Table 1, below, presents key technical and commercialization status details of several fuel cell and hydrogen production technologies. In general, fuel cell technologies for stationary power markets are closer to commercial readiness than they are for transportation markets, particularly in terms of first costs, but important barriers remain for both markets. The general consensus at present is that fuel cells for automotive markets should have costs of perhaps $40-60 per kW (with the low end of the range necessary for close cost parity with conventional vehicles) and durability levels of 4,000-5,000 hours, with stationary markets demanding costs of $800-1,000 per kW and durability levels of ~40,000 hours between major overhauls. For additional details, we recommend the recent NAS/NRC (2004) report titled “The Hydrogen Economy:

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[4] See http://www.stationaryfuelcells.org

[5] See http://www.ch2bc.org

[6] And a broader list including solar PV, wind, and biomass energy and advanced transportation technology organizations would be much longer.

Opportunities, Costs, Barriers, and R&D Needs" and the "Fuel Cell Handbook" published by the National Energy Technology Laboratory (NETL, 2002).

Table 1: Summary Table of Hydrogen Technology Characteristics and Present Status

Technology	**Key Characteristics**	**Technical/Economic Status**
Leading Fuel Cell Technologies		
Molten carbonate fuel cell (MCFC) technology	• High temperature operation (600-700° C.) • Internal reforming capability • Potential corrosion issues	• Early commercial status • Installed costs of about $4,000/kW at present
Proton-exchange membrane (PEM) fuel cell technology	• Ambient temperature operation (<100° C.) • Requires pure hydrogen or hydrogen-rich gas for fuel • Requires platinum catalyst	• Early commercial status • Costs of $3,000-10,000/kW at present and (estimated) ~$200/kW in mass production • Durability of over 2,000 to 3,000 hours unproven
Solid oxide fuel cell (SOFC) technology	• High temperature operation (800-1000° C.) • Internal reforming capability • Low cost materials • Thermo-mechanical stress issues	• Pre-commercial status • Aggressive cost targets of $800/kW by 2005 and $400/kW by 2010 (U.S. DOE SECA program)
Leading Hydrogen Production / Dispensing Technologies		
Alkaline and PEM electrolyzers	• Produce hydrogen from water and electricity • Require approximately 50 kWh of electricity for each kilogram of hydrogen produced	• Alkaline electrolyzers well proven • PEM electrolyzers now commercial • Costs of $1,000+/kW at present • Small-scale "home refueler" electrolyzer devices under development
Autothermal fuel reformers (ATRs)	• Can be used with natural gas, gasoline, diesel, and logistics fuels • Require no external heat source • Combine catalytic partial-oxidation and SMR reactions • Require additional purification systems to produce pure hydrogen	• Under development/pre-commercial • Simpler and more compact than SMRs, and potentially lower cost
Hydrogen purification systems	• Pressure-swing adsorption (PSA) systems can produce hydrogen with purity levels of up to 99.999% • Other methods include palladium and other membrane technologies	• Early commercial status • Relatively high costs for small-scale systems • New PSA designs use rapidly rotating adsorbent beds for enhanced effectiveness
Mobile hydrogen refuelers	• Allow relatively low-cost hydrogen delivery for small-scale refueling applications	• Mobile storage/dispensing units commercially available • Mobile electrolyzers under development
Steam methane fuel reformers (SMRs)	• Well proven at large scale for refinery and chemical plant uses • Under development for small and even "mini" scales • Conventional high pressure reformers require the use of expensive alloy metals for reactor vessels • Require additional purification systems to produce pure hydrogen	• Costs for large-scale systems (50,000-500,000 kg of hydrogen/day) of $80-200/kW of hydrogen production capacity (incl. PSA system) • Costs of small-scale units are much higher at present but expected to decrease with greater production volumes • Low pressure (and potentially low cost) SMR systems under development for small-scale applications

Sources (in addition to author judgments): NETL, 2002; NAS/NRC, 2004; Ogden, 2001.

Hydrogen Production Systems

Hydrogen can be produced and distributed in a variety of ways. These include options whereby hydrogen is produced in large central plants and then distributed by tanker truck (as a liquid), by tube trailer (as a compressed gas), and by pipeline, as well as options where hydrogen is produced onsite at smaller scale.

The main hydrogen production options currently known are as follows, including a short technical and economic characterization of each production source:[7]

Steam Methane Reforming (SMR)

Steam reformation of natural gas (or methane from other sources) produces a hydrogen rich gas that is typically on the order of 70-75% on a dry basis, along with smaller amounts of methane (2-6%), carbon monoxide (7-10%), and carbon dioxide (6-14%). Costs of hydrogen from steam methane reforming vary with feedstock cost, scale of production, and other variables and range from about $2-5 per kilogram at present (delivered and stored at high pressure). Delivered costs as low as about $1.60 per kilogram are believed to be possible in the future based on large centralized production and pipeline delivery, and delivered costs for small-scale decentralized production are projected to be on the order of $2.00-2.50 per kilogram.

Gasification of Coal and Other Hydrocarbons

In the partial oxidation (POx) process, also known more generally as “gasification,” hydrogen can be produced from a range of hydrocarbon fuels, including coal, heavy residual oils, and other low-value refinery products. The hydrocarbon fuel is reacted with oxygen in a less than stoichiometric ratio, yielding a mixture of carbon monoxide and hydrogen at 1200° to 1350° C. Autothermal reforming (ATR) is a third reformation option that combines SMR and POx, with potentially lower costs than SMR and higher efficiency than POx. Hydrogen can be produced from coal gasification POx processes at delivered costs of about $2.00-2.50 per kilogram at present at large scale, with delivered costs as low as about $1.50 per kilogram believed to be possible in the future.

Nuclear-Based Options

Various nuclear energy based hydrogen production schemes are possible, including nuclear thermal conversion of water using various chemical processes such as the sodium-iodine cycle, electrolysis of water using nuclear power, and high-temperature electrolysis that additionally would use nuclear system waste heat to lower the electricity required for electrolysis. Few cost studies of these schemes have yet been conducted, but at large scale and in the future, nuclear thermal conversion of water is believed to be capable of producing delivered hydrogen at costs of about $2.33 per kilogram.

Electrolysis of Water

Hydrogen can be produced via electrolysis of water from any electrical source, including utility grid power, solar photovoltaic (PV), wind power, hydropower, nuclear power, etc. Grid power electrolysis in the United States (U.S.) would

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[7] These characterizations are derived from the delivered hydrogen cost estimates and references shown in Table A-III in Appendix IV. These estimates are discussed in greater detail in Lipman (2004).

produce hydrogen at delivered costs of $6-7 per kilogram at present, with future potential estimated at about $4. Wind electrolysis-derived hydrogen would cost about $7-11 per kilogram at present, with future delivered costs believed to be as low as below $3. Solar hydrogen would be more expensive, on the order of $10-30 per kilogram at present, with future delivered costs of $3-4 estimated to be possible.

Hydrogen from Biomass Gasification

Biomass conversion technologies can be divided into thermo-chemical and biochemical processes. Thermo-chemical processes tend to be less expensive because they can be operated at higher temperatures and therefore obtain higher reaction rates. They also can utilize a broad range of biomass types. In contrast, biochemical processes are limited to wet feedstock and sugar-based feedstocks. At medium production scale and liquid distribution by tanker truck, current delivered costs of hydrogen from biomass would be in the $5-7 per kilogram range. However at larger production scales and coupled with pipeline delivery, delivered costs as low as $1.50 to $3 per kilogram are thought to be possible. Pyrolysis of biomass, another production option, also offers potentially low costs of delivered hydrogen, with costs possibly as low as $1 per kilogram with large-scale production and pipeline delivery.

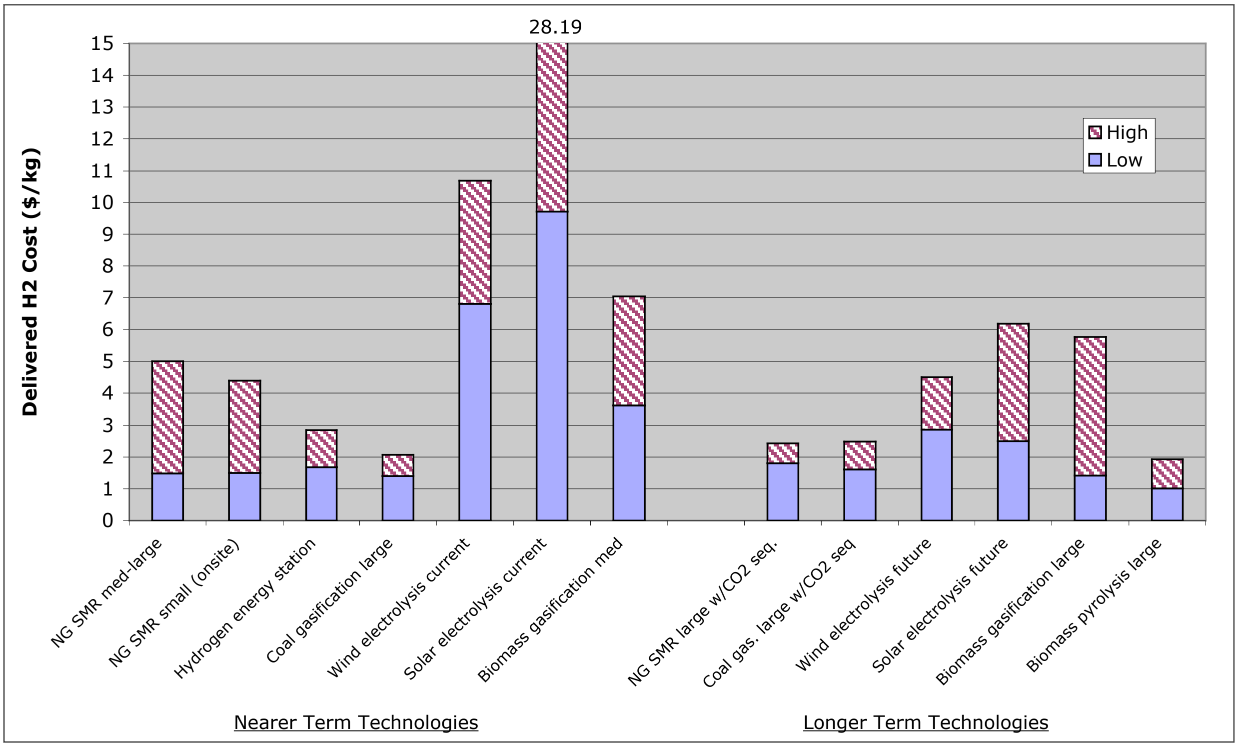
Other Hydrogen Production Options

Hydrogen can also be produced through various other methods, such as direct solar thermal dissociation of water, from municipal solid waste "landfill gas" and waste gases from water treatment plants, and from hydrogen producing algae.

For the fossil fuel-based options, an important consideration is the potential future practicality of carbon sequestration to mitigate the relatively high carbon emissions that are otherwise inherent in these pathways. Carbon emissions can be sequestered in a variety of different ways, including terrestrial, microbial, underground, and oceanic storage solutions. These systems all have varying associated issues and potential costs, with costs and the ultimate integrity of various types of storage reservoirs in particular being uncertain at this time. Cost predictions of $30 per ton of CO_2 sequestered in the long term have been made (equivalent for reference purposes to an additional $13 per barrel of oil or $0.25 per gallon of gasoline), but sequestration costs would likely be higher in the near term (Lackner, 2003).

Figure 4 presents ranges in delivered hydrogen costs from the technical literature. These results are directly taken from various studies and have not been adjusted for different assumptions in the studies (with regard to interest rates, feedstock costs, etc.) to make them more directly comparable. See Appendix III for details of the various cost estimates used to construct the ranges shown in the figure.

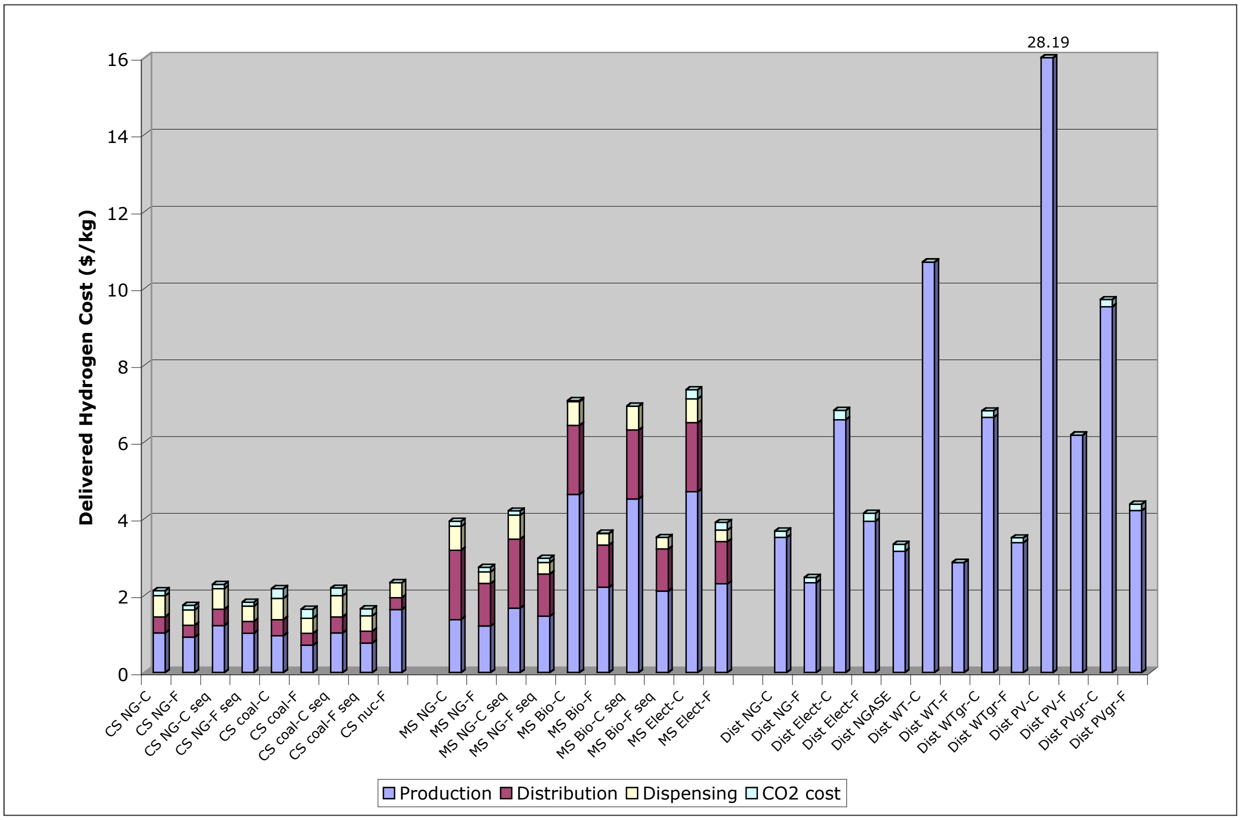
Figure 4: Ranges in Delivered Hydrogen Cost Estimates



Notes: Various sources - see Appendix III for details. The ranges shown are taken from many different sources, including those with assumptions that may be somewhat inconsistent with regard to production scale, interest rates, and other key assumptions. Wider and narrower ranges between high and low costs thus tend to reflect the relative numbers of studies for each pathway, rather than inherent uncertainties in costs for each pathway. Also note that a kilogram of hydrogen contains about as much energy as a gallon of gasoline, but hydrogen-powered vehicles are expected to have ~1.5-3x higher fuel economy than comparable conventional vehicles depending on the technologies used and other vehicle design variables.

Figure 5, below, provides an “internally consistent” look at potential distributed hydrogen costs from various methods from the recent Academies study (NAS/NRC, 2004). The report examines hydrogen production at three different scales, and from various sources including those based on renewable, fossil, and nuclear energy.

Figure 5: One "Internally Consistent" Set of Delivered Hydrogen Cost Estimates



Source: NAS/NRC, 2004. Notes: Bio = biomass gasification; C = current technology; CS = large central station; Dist = distributed production at small scale; Elect = grid-power electrolysis; F = future technology; gr = grid assisted electrolysis; MS = medium-scale; NG = natural gas SMR; PV = solar photovoltaic powered electrolysis; seq = with carbon sequestration; WT = wind turbine powered electrolysis. CO_2 cost = carbon disposal cost and/or carbon tax of $50 per ton.

Hydrogen Distribution and Storage

The technologies for distributing and supplying hydrogen for various uses are generally well known and established, with the exception of very high-pressure (10,000 pounds per square inch [psi]) hydrogen storage and dispensing systems and other innovative hydrogen storage systems. Very high-pressure systems are currently in the research and development stage, and offer high storage densities (about 1.5 times higher than at 5,000 psi) but at somewhat higher compression energy losses. On the other hand, lower pressure compressed-gas storage systems of 3,600-5,000 psi are relatively well proven and are currently being used in many hydrogen and compressed natural gas powered vehicles around the globe.

Hydrogen distribution and supply systems can be classified as being associated with "centralized" production, with significant needs for distribution, and "decentralized" production with much lower or no need for distribution but potentially significant requirements for storage (depending on the relationship between the operation of the production system and end-use requirements). The various hydrogen production methods discussed in the previous section thus imply some differences with regard to hydrogen delivery, particularly with regard to the scale and distribution of production, along with the relative purity of the hydrogen produced. Further, these systems can be distinguished by their potential for near-term deployment, versus longer-term options.

With regard to near-term options for hydrogen distribution, centralized production systems can be coupled with either truck delivery by liquid or high pressure gas “tube trailers,” pipeline delivery, or for hydrogen-powered vehicles in particular, refillable hydrogen “trailers” that can be filled with compressed gas onsite and then placed at off-site locations until refilling is required (see Figure 6 below). For on-site production from SMR and electrolysis, or in the case of chemical plant by-product hydrogen, hydrogen can simply be used as it is produced, or compressed, stored, and dispensed for refueling hydrogen-powered vehicles and/or producing electricity with stationary or automotive fuel cell systems.[8]

Figure 6: Mobile Hydrogen Refueling Unit

Source: Air Products and Chemicals Inc., 2003.

Figure 7 presents several of the main possibilities for delivering hydrogen, showing which technologies are most appropriate depending on the dispensing capacity desired. As shown in the figure, mobile refueling units, delivery of “k-bottles,” and onsite production with electrolyzers are the preferred methods for small quantities of dispensed hydrogen. At very large scales delivery pipelines connected to large production plants and onsite production with reformers are the preferred methods, with various other options possible at intermediate scales.

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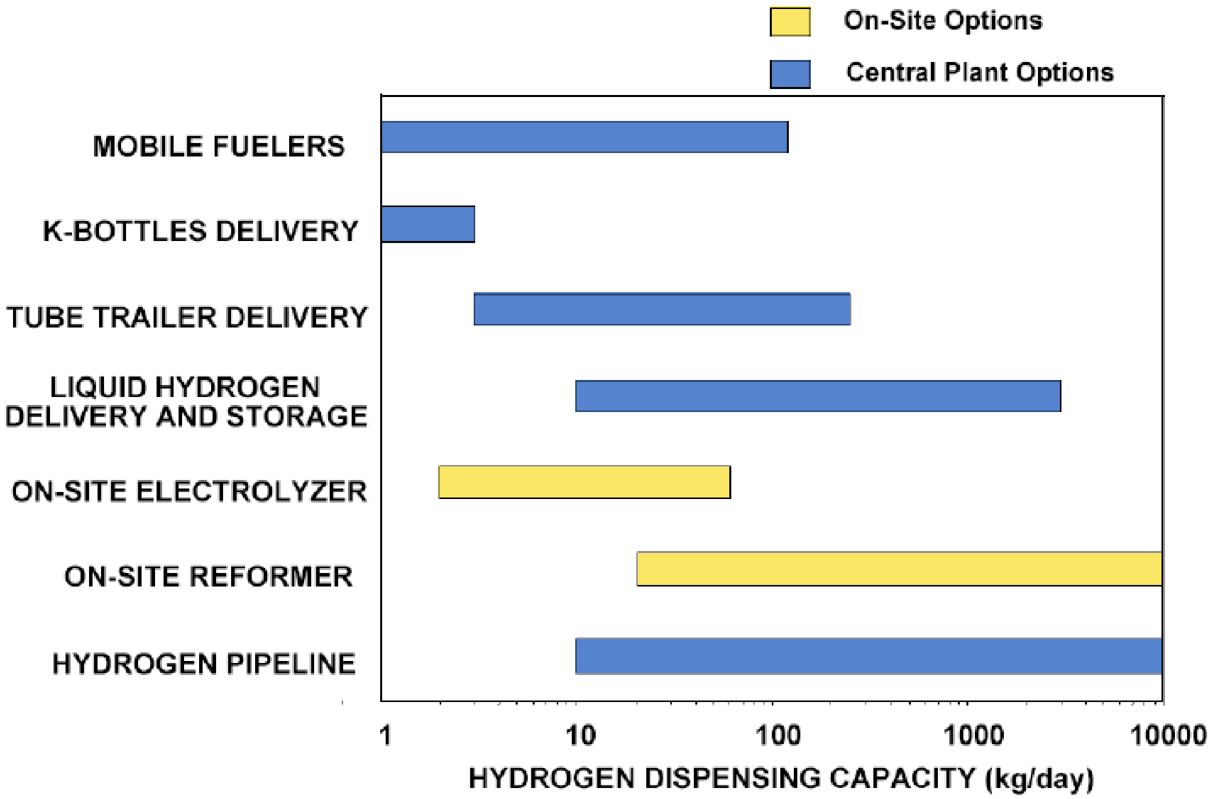
[8] This latter possibility has come to be known as “vehicle-to-grid” or V2G power. See Kempton and Letendre, (1997); Kempton et al. (2002); and Lipman et al. (2004) for details with regard to various possibilities for different types of electric-drive vehicles.

Figure 7: Primary Hydrogen Delivery Options



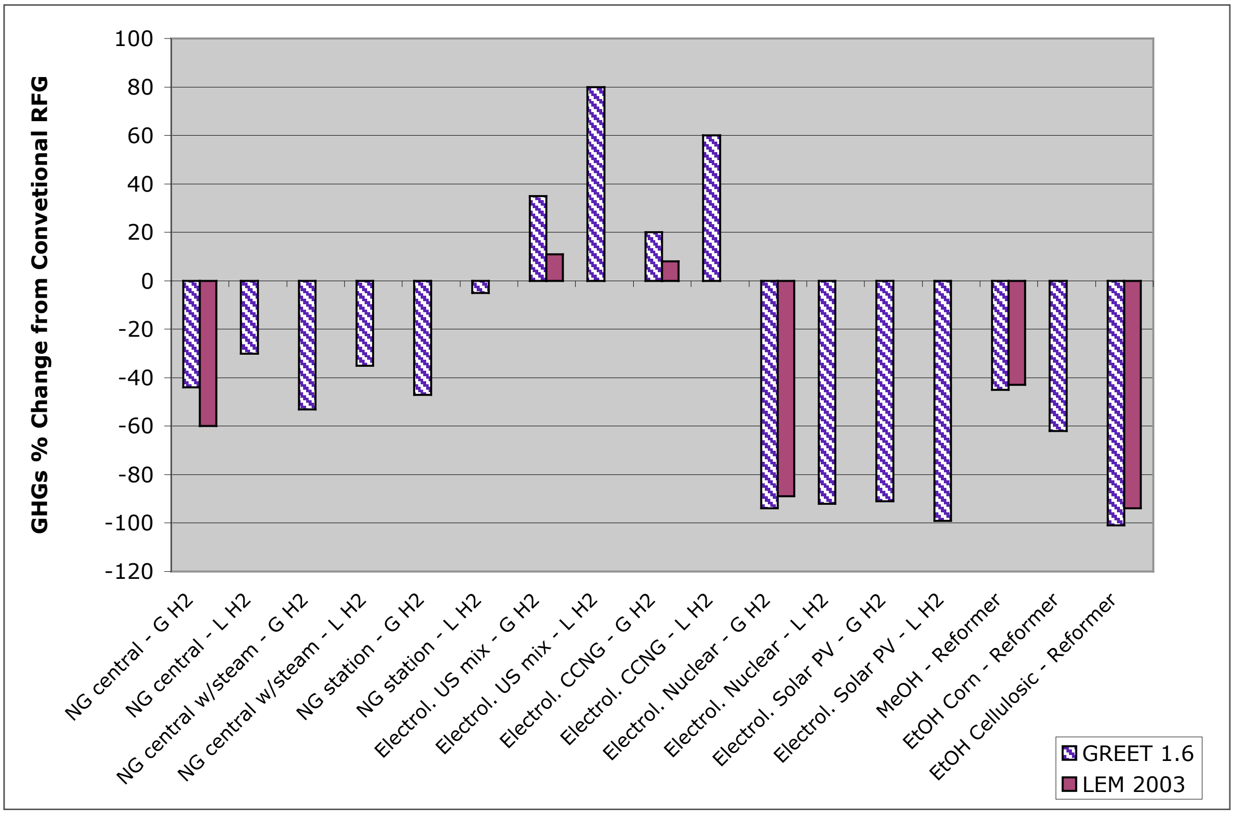
Source: Tiax, 2003.

With regard to overall costs of developing hydrogen infrastructure for vehicles, estimates are difficult to make at this time because they depend strongly on the number of vehicles to be supported and uncertainty in the future costs of various infrastructure components. Near term hydrogen station costs are typically quoted at approximately $400,000 to $500,000 for a station that dispenses delivered hydrogen to $1 million or more for a station that includes a natural gas reformer or electrolyzer for distributed production of hydrogen – but again these figures are strongly dependent on station size and other variables. On a national basis, Byron McCormick of General Motors has estimated the costs of an initial hydrogen infrastructure to support 1 million FCVs that would place a hydrogen-fueling pump within 2 miles of the homes of 70% of the U.S. population and every 25 miles on the interstates connecting the 100 largest cities. He estimates that this 11,700 station national network would cost between $10 billion and $15 billion (McCormick, 2003).

Environmental Impacts of Hydrogen Production Methods

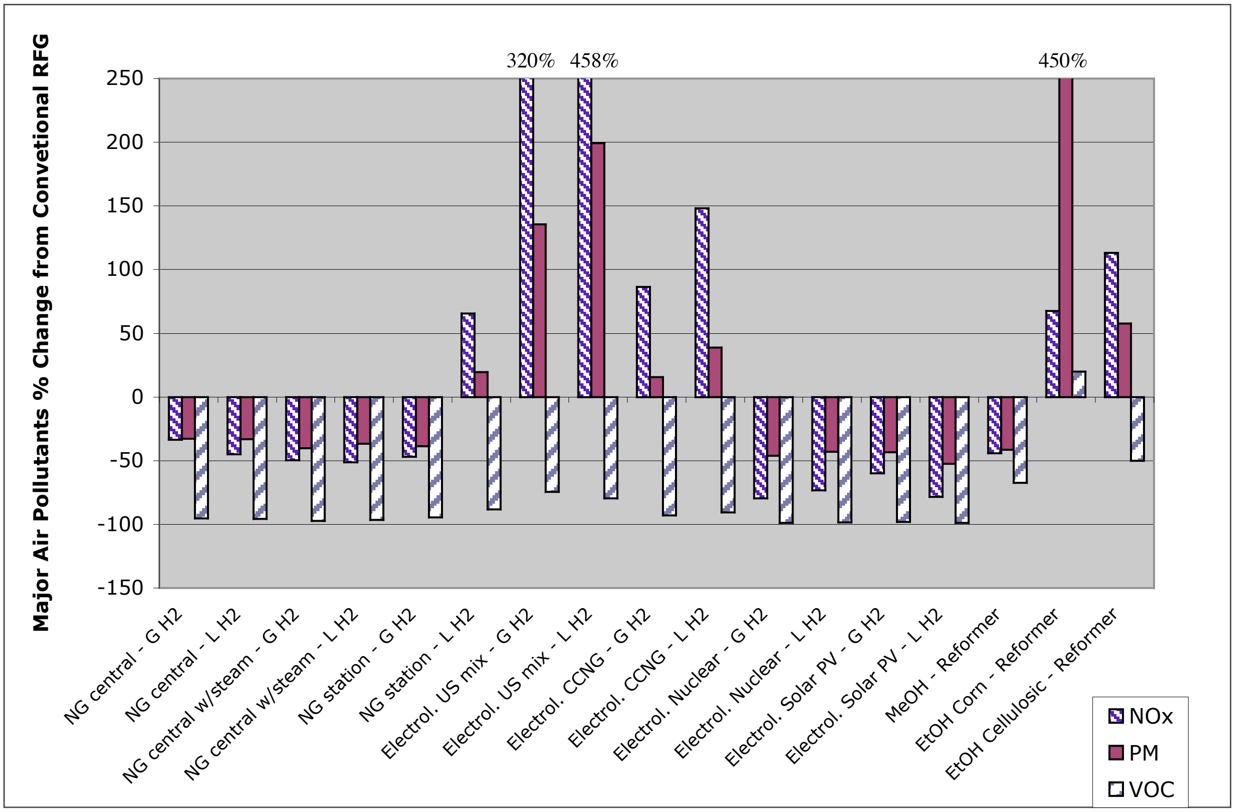
The various possible hydrogen production methods have dramatically differing implications with regard to environmental impacts. Hydrogen production can potentially have very low environmental impacts, hence the considerable interest in its use as an energy carrier, but it can also have relatively high environmental impacts if produced in certain ways. For example, Figure 8 below shows the GHG emissions implications of hydrogen produced in various ways and then used to fuel FCVs, in comparison with using reformulated gasoline (RFG) in conventional vehicles. The estimates shown in the figure illustrate that the GHG emissions of hydrogen production and use in vehicles can vary enormously relative to the emissions from the use of gasoline in conventional vehicles. Depending on the hydrogen production and distribution pathway, emissions can increase by as much as 80% of the level of emissions from conventional vehicles (using the U.S. average grid power mix to produce liquid hydrogen via electrolysis), and decrease by as much as 100% (i.e., be completely eliminated) with biomass and some other renewable pathways. If one goal of the use of hydrogen is to reduce GHG emissions, then the method of hydrogen production and distribution chosen is clearly critical to achieving that goal. The story is similar for other pollutants of concern such as oxides of nitrogen, fine particulate matter, and volatile organic compounds, with large increases particularly in PM and NOx possible with some of the electrolyzer pathways that are based partly or wholly on fossil fuels (see Figure 9)

Figure 8: Greenhouse Gas Emissions from Hydrogen Fuel Cell Vehicle Fueling Pathways



Notes: GREET 1.6 is the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. LEM 2003 is the Lifecycle Emission Model. CCNG = combined cycle natural gas power plant; EtOH = ethanol; G = gaseous; L = liquid; NG = natural gas; MeOH = methanol; PV = photovoltaics; RFG = reformulated gasoline.

Figure 9: **Air Pollutant Emissions from Hydrogen Fuel Cell Vehicle Fueling Pathways**



Source: GREET Model v1.6 (ANL, 2001). CCNG = combined cycle natural gas power plant; EtOH = ethanol; G = gaseous; L = liquid; NG = natural gas; MeOH = methanol; PV = photovoltaics; RFG = reformulated gasoline.

Transition Challenges

The potential expanded use of hydrogen confronts significant remaining obstacles. These challenges include the following:

- For transportation uses, the "chicken or egg" problem where there is no adequate business case for provision of hydrogen refueling infrastructure in advance of vehicle introduction and no way of expanding hydrogen-powered vehicle commercialization beyond limited fleet applications in the absence of this infrastructure;
- Lack of vehicle onboard storage systems for hydrogen that are compact, lightweight, efficient, safe, quick to refuel, *and* inexpensive (with compressed gas at 5,000 psi being the most common present option, but one that is bulky and somewhat expensive);
- The high present cost of making low-carbon hydrogen (via renewable electricity-electrolyzer pathways, biomass gasification/pyrolysis, and fossil fuels with carbon sequestration);
- The high present cost of manufacturing stationary and automotive fuel cell systems;

- Relatively low proven durability of PEM fuel cell technology (on the order of 2,000 hours prior to significant performance degradation); and
- Safety questions and insurance liability issues (both real and perceived).

Addressing these challenges will take a combination of R&D and experimentation. As further progress is made along various lines, new opportunities may become available (such as the ability to store hydrogen without a high degree of compression or liquefaction) and these opportunities may affect the desirability of various hydrogen infrastructure pathways.

For this reason, we advocate a period of experimentation where various hydrogen DG and refueling station concepts and technologies are demonstrated, where example corridor/network hydrogen vehicle refueling is explored, and where major investments are made cautiously – at least with regard to infrastructure to support transportation uses of hydrogen -- until there is a clearer consensus on a "dominant design" for onboard vehicle storage systems and further progress in hydrogen storage, PEM fuel cell, and hydrogen ICE system performance.

There is also an underlying question of whether or not hydrogen production from natural gas for use in hydrogen-powered vehicles in the near term is an acceptable transition strategy as an alternative to conventional and hybrid vehicles running on gasoline. We tend to believe that the answer is "yes" but again stress the need for an overall strategy that considers longer term and even cleaner options. In this regard, recognition must be paid to the potential for technological "lock-in" to natural gas based systems that may not ultimately be able to justify the costs of the transition. Continued development of various hydrogen production/delivery options and exploration of system design flexibility and "forward compatibility" will be important to addressing this concern.

3. Existing Hydrogen Infrastructure Resources in California

California presently has several major hydrogen production facilities – mostly associated with or serving oil refinery requirements for "hydrocracking" and "hydrotreating" gasoline – and 14 hydrogen vehicle refueling stations. Several additional hydrogen-refueling stations are in the planning stages, including those that will be constructed under the DOE hydrogen infrastructure and vehicle demonstration program and the SCAQMD "five cities" program over the next few years. Table 2 lists the existing and planned (publicly disclosed) hydrogen refueling stations in California, along with key characteristics of each station.

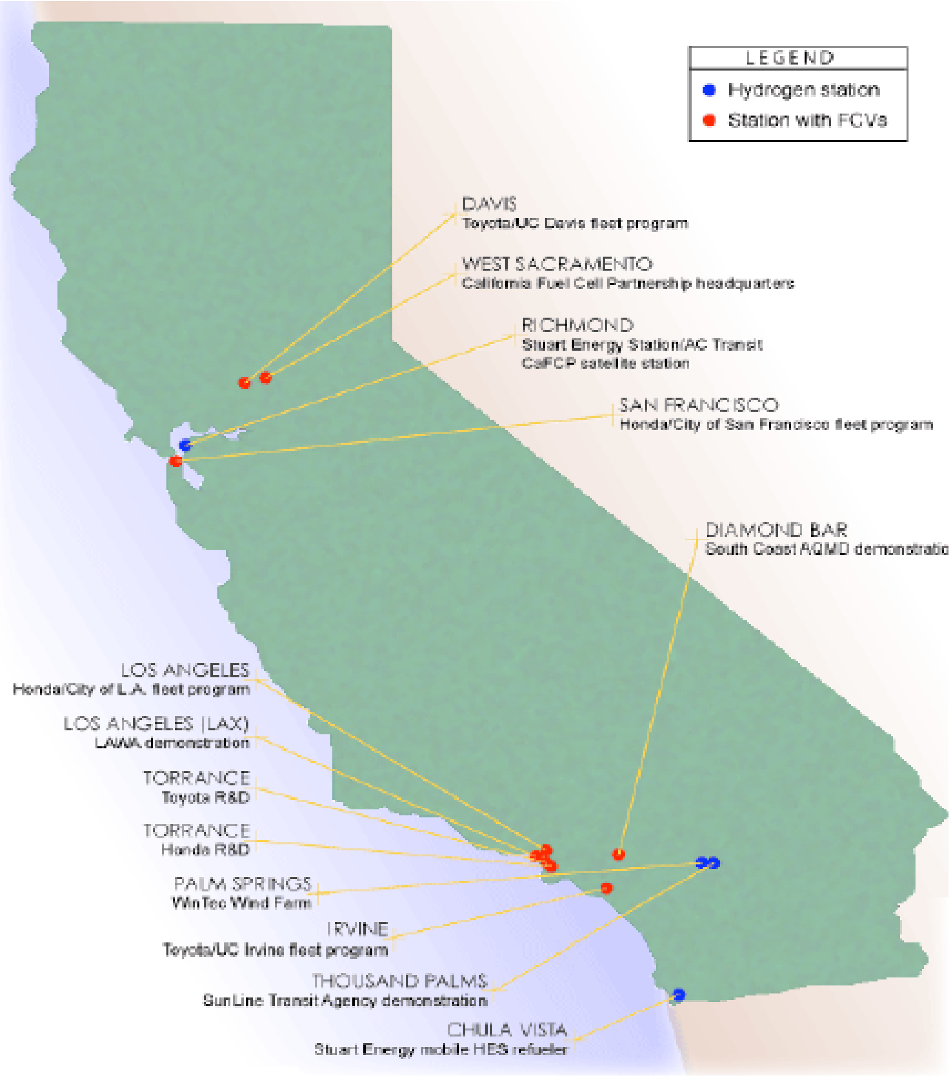
Table 2: Existing and Planned Hydrogen Refueling Stations in California

Location and Nearest Highway(s)	**Hydrogen Form**	**Project/Partners**	**Notes**
*Auburn**	*Compressed gas*	*PG&E, Ztek*	*Under construction*
*Burbank**	*Not disclosed*	*SCAQMD, Quantum*	*SCAQMD "five cities"*
Chula Vista - Hwy 15	Compressed gas	City of Chula Vista	Stuart Energy mobile HES refueler
Davis - Hwys 80 and 113	Compressed gas	UC Davis Hydrogen Bus Technology Validation Program	Hydrogen delivered by Air Products, located at Unitrans maintenance yard
*Diamond Bar**	*Compressed gas*	*SCAQMD*	*Stuart Energy system*
El Segundo - Hwy 405	Compressed gas	Xerox, DOE, UCR, Matrix Engineers, City of W. Hollywood, Kaiser Engineering, SCAQMD	Praxair fueling system; solar photovoltaics, Stuart Energy fueling station
*Huntington Beach**	*Compressed gas*	*SCAQMD*	*SCAQMD "five cities"*
Irvine - Hwy 405	Compressed gas	UC Irvine National Fuel Cell Research Center, Toyota, Air Products	Toyota fleet demonstration program
Los Angeles (downtown) - Hwys 5, 10, and 405	Compressed gas	City of LA, Honda, Air Products	Hydrogen delivered by Air Products
*Los Angeles (airport)**	*Compressed gas*	*SCAQMD, Stuart Energy, Praxair, BP*	*Stuart Energy electrolyzer*
*Oakland**	*Compressed gas*	*AC Transit, ChevronTexaco*	*Hydrogen "energy station" with electricity co-production*
*Ontario**	*Not disclosed*	*SCAQMD, Quantum*	*SCAQMD "five cities"*
Oxnard - Hwy 101	Liquid	BMW N. American Engineering Center	Hydrogen delivered by Air Products
Palm Springs - Hwy 10	Compressed gas	WinTech, SCAQMD, ISE Research	Electrolyzer associated with 3 65 kW wind turbines
*Palo Alto**	*Compressed gas*	*City of Palo Alto, Proton Energy, DaimlerChrysler, CAFCP*	*Electrolyzer-based*
Richmond - Hwys 80 and 580	Compressed gas	AC Transit, Stuart Energy, CAFCP	Stuart Energy electrolyzer at AC Transit facility
Riverside - Hwys 10 and 210	Compressed gas	UC Riverside College of Engineering, SCAQMD	Stuart Energy electrolyzer
San Francisco - Hwys 101 and 280	Compressed gas	Honda and City of San Francisco	Honda Home Energy Station at SF City Transit Yard
*San Jose**	*Liquid to compressed gas*	*Santa Clara VTA, San Mateo Transportation, CEC, BAAQMD*	*Hydrogen delivered by Air Products*
*Santa Ana**	*Not disclosed*	*SCAQMD*	*SCAQMD "five cities"*
Santa Clarita*	Not disclosed	SCAQMD, Quantum, Toyota	SCAQMD "five cities"
Thousand Palms - Hwy 10	Compressed gas	Schatz Energy Research Center, SunLine Transit	Teledyne Energy electrolyzer system
Torrance - Hwys 110 and 405	Compressed gas	Honda	1) Solar-powered electrolysis 2) "Home energy station" with NG reforming
Torrance - Hwys 110 and 405	Compressed gas	Toyota	Contracts with Stuart Energy and Air Products
West Sacramento - Hwys 80 and 99	Liquid to compressed gas	California Fuel Cell Partnership, BP, Shell, Texaco	Hydrogen delivered by Air Products/Praxair

Sources: CAFCP, FuelCells 2000, Energy Independence Now (worldwide web reported data)
Notes: "*" indicates station planned or under construction.

Figure 10, below, shows a map of most of the hydrogen refueling stations in California, and the planned stations that have been publicly disclosed.

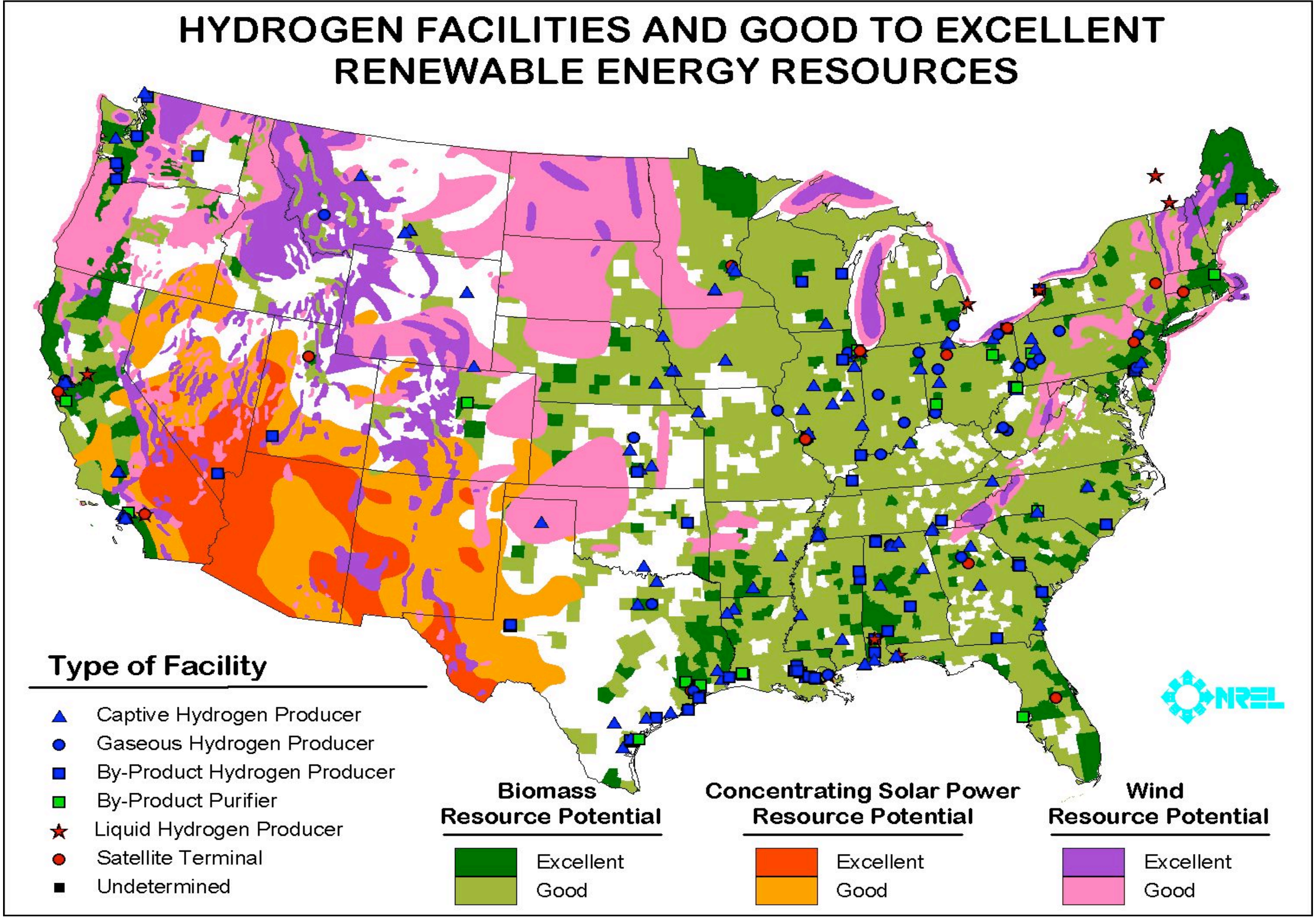
Figure 10: Hydrogen Refueling Stations Associated with the California Fuel Cell Partnership



Source: CAFCP

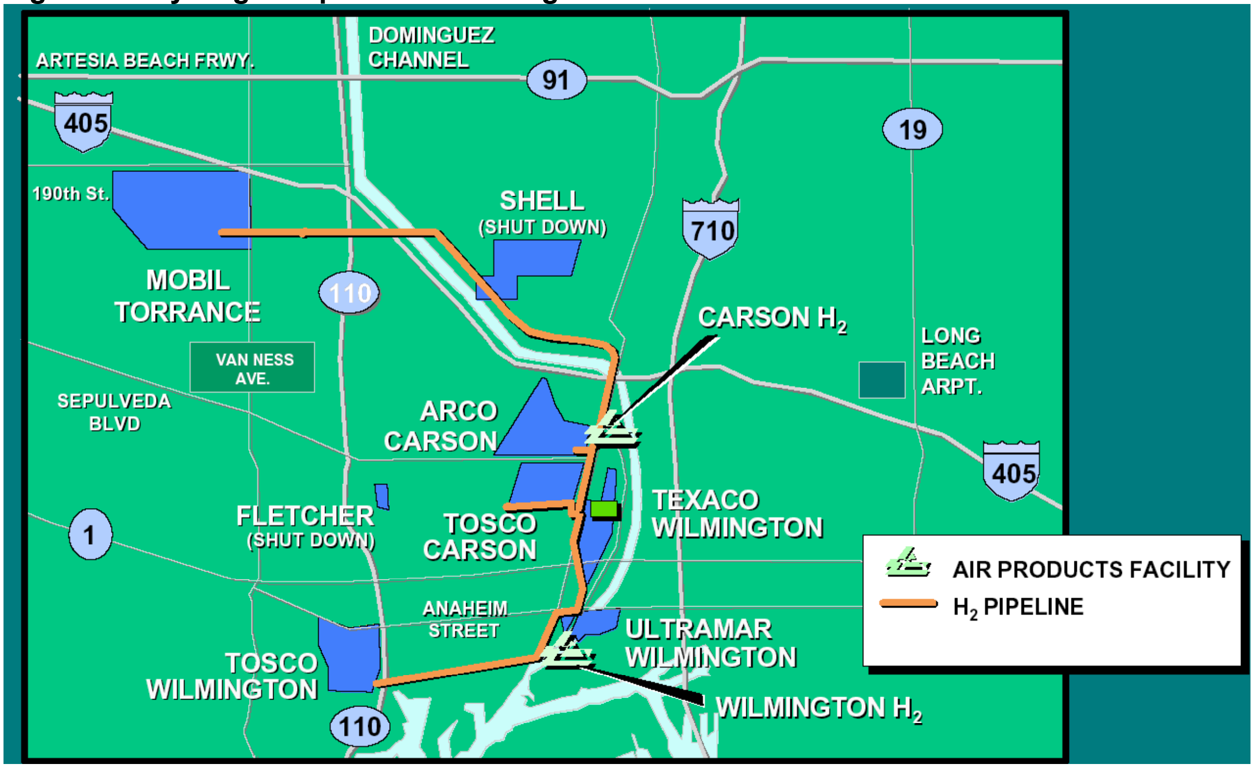
Figure 11, below, presents a map of major hydrogen production facilities in the U.S., along with renewable resource potentials for producing hydrogen from wind power, concentrating solar photovoltaics, and biomass residues from agriculture. As shown in the figure, potential renewable hydrogen production resources are well distributed across the U.S., with every area of the country having at least one of the three major sources of renewable hydrogen available. The hydrogen production facilities represent potential locations where mobile hydrogen refueling units could be refilled, if agreements could be reached with the owners of those production facilities.

Figure 11: Major Hydrogen Production Facilities and Renewable Hydrogen Potential in the U.S.



Also, Air Products and Chemicals Inc. operates a 15-mile pipeline in Los Angeles that connects two of the company's production facilities with six oil refineries. This pipeline could provide fuel for vehicle refueling stations and hydrogen-based DG projects along its current length, and it could also be extended to additional nearby locations. Figure 12, below, shows the location of this pipeline.

Figure 12: Hydrogen Pipeline in Los Angeles



Source: Air Products and Chemicals Inc., 2002

4. Key Elements of a California Hydrogen Plan

Under Gov. Schwarzenegger, California is charting a bold course forward for the development of hydrogen infrastructure and the introduction of hydrogen-powered vehicles. The key elements of the Governor's recent "California Hydrogen Highway Network" Executive Order include (State of California, 2004):

- Designation of the State's 21 interstate highways as the "California Hydrogen Highway Network";
- Development of a "California Hydrogen Economy Blueprint Plan" by January 1, 2005 for the "rapid transition to a hydrogen economy in California" (to be updated biannually);
- Negotiations with automakers and fuel cell manufacturers to "ensure that hydrogen-powered cars, buses, trucks, and generators become commercially available for purchase by California consumers, businesses and agencies";

- Purchase of an increasing number of hydrogen powered vehicles "when possible" for use in California's state vehicle fleets;
- Development of safety standards, building codes, and emergency response procedures for hydrogen fueling stations and vehicles;
- Provision of incentives to encourage hydrogen vehicle purchase and the development of renewable sources of energy for hydrogen production; and
- Ultimately planning and building a significant level of hydrogen infrastructure in California by 2010, so that "every Californian will have access to hydrogen fuel, with a significant and increasing percentage produced from clean, renewable sources."

In his speech announcing the California Hydrogen Highway Network on April 20, 2004, Gov. Schwarzenegger made the following remarks:[9]

> "This starts a new era for clean California transportation. These vehicles produce no emissions and no smog. They will clean the air and get rid of the smog that is hanging over our cities, and reduce the health problems caused by our pollution. Your government will lead by example and start using hydrogen-powered vehicles. And while we invest in a clean California, I will make sure that we get federal funds to support our innovative efforts.
>
> As I have said many times, the choice is not between economic progress and environmental protection. Here in California growth and protecting our natural beauty go hand in hand. It goes together. A healthy environment leads to a healthy economy and a more productive workforce, and a better quality of life for everyone."

The vision of the Schwarzenegger administration for the increased use of hydrogen is for the most part achievable in our view,[10] but the challenges to doing so are significant and should not be underestimated. While there is a tremendous potential upside for California, the U.S., and the world in pushing forward with the development of hydrogen fuel for transportation and stationary power production, there are also several potential pitfalls. These include primarily:

1) Infrastructure cost challenges and the associated risk of "stranded investments" should the introduction and consumer uptake of hydrogen-powered vehicles lag relative to expectations;
2) Continued progress with gasoline-electric HEVs, plug-in HEVs, and lithium battery powered EVs as competitors to hydrogen vehicles; and
3) The ciritical issue of how hydrogen is to be produced both economically *and* with low local and global environmental impacts.

This California Hydrogen Highway Network effort should be guided by careful reviews of progress in technology commercial readiness, with flexibility for adjustments in goals and expectations along the way. Importantly, the date of *2010 should not be seen as more than a*

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[9] See Appendix V for the Governor's full remarks.

[10] As long as the 2010 infrastructure goal is interpreted loosely, with "every Californian having access to hydrogen fuel" taken to mean "every Californian *can* have access to hydrogen fuel" -- meaning not that hydrogen infrastructure is yet fully available, but where barriers to the use of hydrogen have been greatly reduced through codes and standards development and a range of hydrogen production and delivery systems for different scales of applications are available (albeit likely still at high cost).

milestone on the path of a much longer journey. The actual widespread use of clean and renewable hydrogen is a much more distant goal, and the emphasis through 2010 should be on experimentation, learning, basic R&D on key technologies, scale-up from individual demonstrations to pilot networked infrastructure “corridors,” codes and standards development, and demonstration of system safety. In this way the State can close in on a consensus for the best patterns and strategies for deployment of truly widespread hydrogen infrastructure. *We think it is of great importance that the movement to hydrogen-based energy systems not be rushed* in a way that sets goals that are too ambitious and that then risks failure in the eyes of the public. In 2010 we should for the most part still be planning and experimenting, and only slowly building out the long-term hydrogen production and refueling network for California.

In order to meet the broad energy and environmental challenges that the State faces, we suggest that California embark on a major science and technology initiative for renewable energy, energy efficiency, and hydrogen and fuel cells. California is uniquely positioned to lead the world in these efforts due to the following confluence of factors:

- California is home to several of the world’s leading research institutes for renewable energy and hydrogen/fuel cells. These include various branches of the University of California and the California State University systems -- UC Berkeley, UC Davis, UC Irvine, UC Riverside, and Humboldt State University; world-class private universities such as Stanford University, the California Institute of Technology, the Claremont Colleges, and the University of Southern California; and five major U.S. government national laboratories -- the Lawrence Berkeley National Laboratory, the Lawrence Livermore National Laboratory, the Sandia National Laboratory–Livermore, the Jet Propulsion Laboratory, and the NASA-Ames Research Center;
- California also is home to several other major industrial groups and public/private partnerships that add additional important renewable energy, hydrogen, and other clean energy technology R&D capabilities (e.g., the CAFCP, the CASFCC, various DOE and CEC sponsored partnerships, the Electric Power Research Institute, WestStart-CALSTART, Air Products and Chemicals Inc.,[11] PowerLight Corp., Aerovironment Inc., Sun Light and Power Company, ISE Corp., Anuvu Inc., and Quantum Fuel System Technologies Inc., among others);
- California has developed innovative clean energy technology financing mechanisms such as CAEATFA, “Green Wave,” and utility-sponsored clean technology incubator and natural gas/electricity DSM programs.
- California has additional progressive policy and regulatory environment for hydrogen technologies and renewable energy, including the state RPS, the ZEV mandate, and the Pavley Law (discussed above), as well as technology deployment incentive programs such as the California Public Utilities Commission (CPUC) Self-Generation Incentive Program (SGIP) and the CEC Emerging Renewables Buy-Down Program.

With regard to this last point, State funding is available to assist with eligible renewable energy, stationary fuel cell, and other DG project capital costs through both the CEC and CPUC programs. The CPUC SGIP and the CEC Emerging Renewables Buydown Program are

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[11] Air Products and Chemicals Inc. has a major presence in California but is headquartered in Pennsylvania.

complementary programs that incentivize the installation of renewable and other clean energy technologies. The SGIP is the larger of the two programs, and is generally considered to be the most successful distributed generation program in the U.S. See Appendix IV for specific details of these clean energy/DG incentive programs.

In addition to these research groups and broad policy thrusts, California has world-class expertise within several of its governmental agencies. These include the following, along with a short description of the potential role that each can play in the science/technology initiative and the hydrogen infrastructure and vehicle deployment efforts:

- California Air Resources Board (ARB) – Has a leadership role with regard to the implementation of the ZEV mandate and other statewide air quality programs, the implementation of the Pavley GHG law, and the operation of the CAFCP and the CASFCC; continuation of requirements for "gold standard" ZEVs in the ZEV mandate may be critical to the introduction of hydrogen-powered vehicles in California; continued support for the CAFCP and the CASFCC can continue to raise the profile for hydrogen technologies worldwide.
- California Department of Transportation (Caltrans) – Also has a critical role to play with regard to experimenting with DG in maintenance facilities, potentially making available "rights-of-way" around the State for hydrogen projects, and testing hydrogen-powered vehicles in the Caltrans vehicle fleet.
- California Energy Commission Public Interest Energy Research (PIER) Program – Currently funds R&D for the electricity sector, including significant support for renewable sources of electricity and with some support for hydrogen research that is relevant for electricity ratepayers in California. Given the increased interest in hydrogen in the State and the important potential impacts on the State's electricity supply/demand situation, PIER research priorities should be re-oriented to provide greater support for hydrogen and renewables-to-hydrogen R&D.
- Department of General Services (DGS) – Responsible for procurement and therefore has an important role to play, especially in working with the State Finance Department on procurement for renewable energy, DG, and hydrogen systems.
- Investor-owned and Municipal Electrical and Gas Utilities – May undertake efforts to meet California RPS goals on or ahead of schedule; voluntary municipal utility compliance with RPS goals; support for end-use efficiency programs for both electricity and gas; support for innovative renewables/hydrogen R&D and demonstration programs.
- Municipalities – Can provide local demonstration project support; permitting/codes and standards compliance assistance; conduct public education programs.
- Regional Air Quality Management Districts (AQMDs) – Can provide guidance and information on DG and hydrogen project permitting requirements; prioritization of and streamlined permitting for public/private clean air projects that are designed primarily for the public good; clean air technology validation and demonstration project partnership and support; public outreach on the benefits of clean air, energy-efficiency, and low-GHG emission technologies.

More specifically, with regard to California's efforts in pursuing the Governor's "Hydrogen Highways" vision, we believe that a promising strategy could include pursuit of the following nine key elements:

1) Build on existing projects, programs, and energy and transportation infrastructure and pursue aggressive but incremental steps as the vehicle market develops;
2) Use public/private partnerships to leverage resources and combine expertise;
3) Explore the integration of hydrogen infrastructure development with distributed electrical power generation (e.g. hydrogen "energy stations") and innovative mobility systems (e.g., shared-use vehicle services facilitated by electronic and wireless reservation and communication technologies);
4) Focus initial hydrogen infrastructure developments on prioritized "key corridors" and in a coordinated fashion, and include experimentation with innovative low-cost hydrogen distribution options (e.g. mobile dispensing platforms and integration with activities with large fleet and retail companies);
5) Emphasize and lay out a clear plan for using California's domestic resources to produce hydrogen cleanly, and increasingly from renewable sources, and prioritize R&D on electrolyzer and biomass-to-hydrogen systems;
6) Experiment with hydrogen for off-road uses including forklifts and other vehicles operating inside buildings, construction site applications, and in maritime and agricultural settings;
7) Demonstrate hydrogen safety and reliability through development of codes and standards for hydrogen energy systems;
8) Use State action to encourage all hydrogen refueling stations, including those owned by public and private fleets, to be available to the public (wherever practical); and
9) Use existing and new mechanisms, such as the partnership among Caltrans, ARB, and CEC, to coordinate State agency activities as appropriate.

These points are discussed below, followed by a proposed set of evaluation criteria that State agencies might wish to use or adopt to evaluate the attractiveness of particular hydrogen infrastructure projects. This is then followed by Section 5, which presents an illustrative hydrogen infrastructure and vehicle deployment timeline for California along with discussion of potential project financing mechanisms.

Key Elements of a Potential California Hydrogen Energy Transition

In addition to the general point that the expanded use of hydrogen in California should critically be part of a larger effort for clean and sustainable energy more generally, we make the following suggestions for the State to consider as it explores and experiments with greater use of hydrogen for transportation and power generation uses.

1) Build on Existing Infrastructure and Projects

Although hydrogen's potential use as a transportation fuel is novel, it is widely used in industrial, chemical, and food-production industries today. Hydrogen infrastructure development in California will therefore benefit from considerable resources already in place and can be leveraged from a considerable infrastructural, institutional, and program/project base. Examples of these resources include the following: the substantial hydrogen production facilities that are present in California among industrial gas suppliers and oil refineries (and the several miles of hydrogen pipeline in Southern California); the aggressive South Coast Air Quality Management District (SCAQMD) program of promoting hydrogen infrastructure development in that region, now with several operating hydrogen facilities; the DOE's contribution $190 million dollars to California and other states for additional hydrogen infrastructure projects in the coming years; and the extensive natural gas infrastructure that is widely available throughout California. This existing core of projects can be complemented by others that are added in a staged fashion, and that are leveraged from the existing resource base -- and future resources such as the expansion of renewable energy in California. This resource base can be accessed through strategic partnerships and with careful attention paid to project location and design to maximize benefits.

2) Promote Intrastate and Interstate Public/Private Partnerships

A powerful model for grappling with many of the key issues associated with hydrogen infrastructure development is the establishment of public/private partnerships to jointly contend with project financing arrangements, regulatory and permitting issues, project liability concerns, and overall project financial risk management. The capital required for an aggressive development of hydrogen infrastructure cannot come from the private or public sector alone, but must combine the two through a mix of appropriate public revenue sources that are highly leveraged with contributions from the industries that ultimately will gain from the initial investments. Working together, private sector concerns that wish to be involved in infrastructure projects and the public sector ones that are tasked with encouraging them can more readily address regulatory and permitting issues, spread learning from project experience around the State, and enter into arrangements that help to mitigate project risk. California has the role of an environmental and style leader, and it is therefore attractive to private sector interests as a high profile early market for hydrogen and other clean energy technologies.

Furthermore, there is a potentially important role for interstate partnerships to develop broader hydrogen corridors and partnerships for renewable energy development. In addition to efforts within California, the State can benefit from leveraging efforts with nearby states (such as the "Western States Global Warming Initiative") and from broader initiatives such as the "Apollo Alliance"[12] for energy efficiency and clean energy development. Again, due to California's position as a center for clean technology industries, successful interstate and national efforts for renewable energy and energy efficiency are likely to confer both direct and indirect benefits to the State.

3) Integrate Hydrogen Infrastructure with Distributed Power Generation and Innovative Mobility Systems

Innovations in fields complementary to hydrogen infrastructure are occurring in the areas of distributed power generation and intelligent transportation and mobility systems. We believe that the use of fuel cells and hydrogen energy for stationary power is likely to proceed well in advance of most transportation uses, as the cost targets and hydrogen fueling issues are much more readily attainable and manageable for this sector (though durability is a significant challenge for stationary applications of PEM fuel cell technology). As the use of fuel cells/hydrogen expands for power generation, there may be significant "spillovers" that will

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[12] The Apollo Alliance is a broad coalition of environmental groups and labor unions that is advocating a 10-point agenda for energy independence and economic growth. See http://www.apolloalliance.org for details.

slowly make FCVs more attractive – perhaps first for transit and other fleet vehicles and potentially for privately owned vehicles at some point in the future.

More specifically, concepts such as stationary fuel cell-based “hydrogen energy stations” could allow hydrogen infrastructure to be introduced in ways that minimize the resources that need to be committed to providing hydrogen-refueling infrastructure ahead of widespread vehicle introduction. This could be accomplished by using some of the hydrogen fuel produced onsite to produce electricity, thereby displacing grid power purchases (including at government facilities). Even where not actually profitable in an overall sense, due to high near-term fuel cell costs, such stations can reduce the early losses associated with the provision of hydrogen infrastructure to small numbers of vehicles through their dual-function capacity (powering a building and a small hydrogen vehicle fleet), and then can ultimately become profitable (see Lipman et al., 2002 for detailed economic analysis of this concept). In the longer term, hydrogen FCVs themselves can act as distributed power generation and utility grid “ancillary service” resources, potentially increasing the economic returns on early hydrogen infrastructure development and FCV deployment (Kempton *et al.,* 2001; Lipman *et al.,* 2004). Due to the complexities involved in the potential interplay between the electricity and transportation sectors, we feel that more analysis along these lines is needed to more fully grasp the key issues and potential benefits.

Meanwhile, in the field of intelligent transportation systems (ITS), onboard vehicle navigation systems in vehicles could provide geographical information on hydrogen fuel availability as well as hydrogen cost, and could even allow “fuel reservation” services where hydrogen producers could schedule early demand for hydrogen fuel to guarantee availability and optimize production and storage. Efforts to introduce hydrogen should interface with ongoing vehicle instrumentation and electronics innovations to explore these possibilities, such as the Integrated Network of Transportation Information (INTI) program – a collaborative effort among several major automakers and suppliers of ITS technology. Efforts to introduce hydrogen could also benefit from vehicle placements in shared-use vehicles organizations that are gaining popularity in California’s metropolitan areas and in other large cities around the world. These organizations could expose individuals to the use of hydrogen-powered vehicles without the risks (real and perceived) of private ownership and could also help to establish the safe use of hydrogen vehicles and demonstrate their advantages.

These and other concepts for combining distributed power generation and ITS with hydrogen infrastructure deployment efforts are highly promising and should be explored in near-term hydrogen infrastructure deployment efforts. Due to the many possible options and the complexities of introducing a new vehicle fuel, it is only by experimenting with what is now becoming possible with the confluence of innovations in different fields that project developers and researchers can understand what the best options may be.

4) Focus Initial Hydrogen Infrastructure Developments On Prioritized “Key Corridors”

We believe that the best course forward for California for the development of a hydrogen refueling infrastructure, based on what we know at present about the options for and costs associated with developing it, is to proceed with in a staged manner where subsequent phases are not pursued until key milestones on the vehicle introduction/hydrogen demand side are met. In this way, risks of stranded assets can be managed to some extent as the introduction of the vehicles proceeds in tandem with the layout of the infrastructure. However, in order for vehicle ownership to be attractive in a given region -- once ownership extends beyond fleet applications and to the consumer sector -- a certain critical mass of refueling stations must be present. Unless home refueling with hydrogen proves successful, and we are skeptical of this at present for cost reasons, the conventional wisdom is that some 10 to 20% of hydrogen stations must be equipped with hydrogen fuel dispensing capability before vehicle ownership is attractive.

However, this need not be done all over the State at once. The main urban areas can be targeted with initial vehicle introduction and hydrogen infrastructure can first be developed along specific key regional corridors and for powering building/facilities, as well as for supporting a limited number of vehicles. The infrastructure can then be expanded further in stages as the hydrogen fuel market develops and a critical mass of vehicle users is gained. This suggests that hydrogen vehicles will initially be somewhat confined in their area of operation, but with the development of at least a sparse infrastructure along the major State highways as a second major phase of development, this constraint can be rapidly eased. The fundamental point is that investments can be made purposefully in ways that can be scaled up (e.g., to power both facilities and vehicles), thus reducing risks of stranded assets while also satisfying the minimal infrastructure needs of initial vehicle users (albeit not everywhere at once).

5) Emphasize Producing Hydrogen Cleanly and Renewably (For the Long Term)

The benefits of hydrogen use are strongly dependent on the manner in which hydrogen is produced. Hydrogen is an energy carrier, akin to electricity, and it can be produced in many different ways with dramatically varying environmental impacts. As noted above, California has abundant natural resources that can be used to produce hydrogen cleanly and sustainably, and these methods should be pursued for hydrogen production to the extent possible. However, in the transition period it will be difficult to rely heavily on renewable sources of hydrogen because these are relatively high cost options at present. As the costs of hydrogen end-use technologies decline, and renewable hydrogen production systems become more well-developed and lower cost, using these sources for hydrogen will become more practical. The State's RPS program, which calls for increasing amounts of the electricity purchased by investor-owned utilities in the State to come from renewable sources, may also help in this regard. See Section 6 below for a proposed "clean hydrogen standard" that would be akin to the State's RPS in the electricity sector.

We note here that natural gas will likely be used as an initial source for much of the hydrogen used in California. It is important to realize that this does in most cases provide environmental and energy use benefits relative to conventional gasoline-powered vehicles -- but perhaps only marginally relative to advanced HEVs and in any event much lower benefits than are possible with the use of cleaner and more sustainable hydrogen production strategies. In the "big picture," much of the true promise of hydrogen lies in its ability to be combined with renewable production sources to produce larger benefits, but as part of the transition interim investments will need to be made in production systems that are not environmentally optimal such as those based on natural gas. The key is to place these investments in the context of a larger vision and transition scenario, and to explore system flexibility and "forward compatibility" concepts, so that the State does not become "locked in" to these marginal-benefit solutions and can progress beyond them.

6) Experiment with Hydrogen for Off-Road Transportation Uses

Off-road applications for hydrogen include forklifts and other vehicles operating inside buildings, construction sites, agricultural settings, recreational areas, and ferries and other maritime vessels. Since hydrogen fuel cells can be zero-emission with the exception of water vapor (when operated on pure hydrogen), they may have key early niches in indoor operational settings where the only competitors are battery technologies. Other off-road applications such as construction sites and agricultural and marine settings may also be attractive because the conventional vehicles used in these locations have been relatively uncontrolled from an emissions perspective to date, and the use of hydrogen may therefore have large potential benefits. Commercial ports provide interesting applications for both stationary fuel cells and hydrogen used onboard maritime vessels (perhaps selectively when they are nearing or moored at the port) due to pollution concerns that often are present in these locations.

7) Demonstrate Hydrogen Safety and Reliability

The development of suitable codes and standards and demonstration of safety and reliability for hydrogen systems will be critical in addressing potential safety concerns on the part of the general public and public officials. This codes and standards work is well underway under the guidance of the International Code Council, the U.S. National Fire Protection Association, the National Hydrogen Association, and DOE, and in partnership with industrial and other groups. However, considerable work remains with regard to developing additional standards and in examining and refining the suitability of existing standards. A key aspect of early demonstration and pilot projects should be to document safe and reliable operation, as well as any safety issues that arise so that experiences can be globally shared with regard to potential safety issues and risk mitigation strategies.

8) Encourage Hydrogen Refueling Stations to be Available to the Public Where Practical

Since many hydrogen refueling station development projects -- even those designed to serve private fleets -- will require State agency participation at various levels, including potential funding assistance, the provision of this assistance could be made to depend in some part on the station operator's plans for providing fuel to the general public. Eventually the development of hydrogen infrastructure may reach a level where access for the public to refueling stations for private-fleets may no longer be necessary, but initially these stations could provide critical refueling locations for the broader hydrogen vehicle market. These include State fleets (with the government as an "early adopter") as well as transit systems, where hydrogen-powered vehicles are likely to be incorporated well before they are available to the general public. This will entail safety and liability concerns that will need to be addressed, but State action to help address these concerns could be helpful and limiting or withholding public assistance for such projects would be a powerful incentive for such stations to be designed and operated with public access as a possibility. The potential for proposed hydrogen projects to offer public access if and when needed could be used among other evaluation criteria for project assistance requested from the State (see below).

9) Use Existing and New Mechanisms to Coordinate State Agency Activities

The effort to develop a hydrogen infrastructure will span several state agencies including the California Environmental Protection Agency and ARB, CEC, Caltrans, the Department of Finance, DGS, and the Technology, Trade and Commerce Agency, among several areas. To maximize the use of resources and allow for coordination and cooperation in the public-sector side of hydrogen project planning, financing, and permitting, it is imperative that these agencies work together as well as possible. Existing agreements such as the "partnership memorandum of agreement"[13] among Caltrans, ARB, and CEC can be invoked and perhaps extended to assist in this regard to economize on State efforts and cut through bureaucratic red tape. Agencies can engage in partnerships based on each agency's unique capabilities and resources, and in partnership with each other and the private sector. An example might include

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[13] The partnership memorandum of agreement among Caltrans, ARB, and CEC was signed in the summer of 2001. The purpose of this agreement is to pledge that the parties will, to the greatest extent possible, use their staff and financial resources to work cooperatively on energy efficient and environmentally sound transportation improvements for California. The objective is to ensure timely planning, implementation, and research of innovative transportation projects that facilitate modal integration, protect the State's environment, and promote energy efficiency.

combining a section of a Caltrans right-of-way for the construction of a hydrogen refueling station with a local AQMD's permitting assistance, leveraged project capital cost assistance from the CEC, and additional assistance from DGS with regard to access for statewide vehicle fleets.

Proposed Evaluation Criteria For Hydrogen Infrastructure Projects In California

As discussed above, California currently has 13 hydrogen refueling facilities of various types, and immediate plans for about a dozen more. To the extent that new stations are to be permanent or semi-permanent, we feel that it is important to consider the construction of the stations in the context of a larger plan for continued experimentation with hydrogen in California.

The development of the "Hydrogen Highways Implementation Advisory Panel" as part of the California Hydrogen Highway initiative is a positive development in this regard, as the panel will be able to help coordinate and organize efforts to construct new hydrogen infrastructure. Below is one set of potential evaluation criteria for assessing the overall potential value of new hydrogen infrastructure projects. To the extent that future projects benefit from State support or are subject to state approval or permitting authority, these criteria could be used to help to assure that projects are appropriate and that the potential benefits of the projects are maximized.

Table 2: Proposed Evaluation Criteria for State-Assisted or Approved Hydrogen Infrastructure Projects

Criterion	**Notes**
1) Station satisfies accepted codes and standards for safe operation and public access	Continued codes and standards development and documentation of safe operation will be important in the near term to addressing important safety concerns with hydrogen
2) Project is well-located with regard to existing stations, "clean fuel corridor" initiatives, and/or early hydrogen-powered vehicle placement locations	Coordinated hydrogen infrastructure development can help to maximize the benefits of early infrastructure projects
3) Station will be or has the potential to be accessible by the general public in future years	Provision for public refueling is not important near-term, but is desirable as part of a longer-term strategy
4) Station will dispense hydrogen produced in a clean and sustainable fashion, or has the capability to be modified/retrofit in the future to do so	The level of State support for hydrogen projects could be tied to the extent to which the hydrogen is produced with low air pollutant and GHG emissions and from sustainable feedstocks
5) Station design achieves near-term goals apart from provision of hydrogen for vehicle refueling	Stations that provide multiple functionality (e.g. distributed power generation as well as hydrogen dispensing, CNG dispensing as well as hydrogen, etc.) can improve early station economics and reduce risks of stranded assets
6) Station design and location conforms with other municipality and regional agency goals	Multi-agency perspectives should be considered with regard to station design and location

5. A California Hydrogen Strategy

As suggested above, we believe in a hydrogen transition strategy that sets broad goals for the future, but that at the same time does not assume success, and that is staged with key milestones and transition elements. One potential set of fundamental stages for hydrogen vehicle and infrastructure growth and development is as follows, along with key milestones that may be achieved:

> Initial Stage – Experimentation with hydrogen technologies for both stationary power and transportation applications. Hydrogen vehicle ownership and refueling at facilities and within fleets owned by state agencies, universities, public and public/private transit service providers, and municipal electric utilities. Large private fleets owned by hydrogen industry stakeholders (large oil companies, investor-owned utilities, automobile manufacturers, etc.) encouraged to begin experimenting with hydrogen-powered vehicles. Provision for stations to be available to the public in a forward-looking manner where possible and practical. Considerable experimentation with station design and location type, as well as with vehicle technologies (e.g., fuel cell, hydrogen combustion/electric hybrid, etc.). Focus on *key corridors* of development for permanent infrastructure to explore networked refueling, with agile refueling infrastructure (mobile refueling units of various types, including mobile storage trailer and mobile electrolyzers and reformers) used selectively in outlying areas. Natural gas-based hydrogen dominates, along with experiments with electrolysis and biogas. Distributed power generation with hydrogen and linkages to innovative mobility systems potentially important to lowering the costs and increasing the exposure to the public of hydrogen technologies. Considerable efforts for hydrogen codes and standards development.
>
> Timeline and Milestones: Expected to be at least through 2008, with up to 1,000 hydrogen-powered vehicles in California and perhaps 50-60 refueling locations.
>
> Growth Stage – With continued progress in hydrogen technologies, developments may move beyond the initial stage to this growth phase. Expansion of hydrogen use in stationary applications, and continued introduction for transportation uses. Under the current ZEV mandate, the minimum number of ZEVs in the State would be 2,500 in the 2009-2011 timeframe (with up to half battery EVs and the remainder FCVs), with many more possible depending on the compliance path chosen by each major vehicle manufacturer.[14] With the increase in vehicles, additional hydrogen refueling stations are added through public/private partnerships guided by the State and regional agencies and municipalities and, depending on the growth of the hydrogen vehicle fleet, possibly the triggering of a clean fuel refueling infrastructure provision of the California Code of Regulations (see below). Hydrogen infrastructure spreads beyond key corridors into broader networks and coverage across more of the State.

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[14] The ZEV rules are complex and offer significant flexibility, but up to about 10,000 FCVs could be added in each year beyond 2008.

Timeline and Milestones: 2008 through at least 2011 with from 1,000-20,000 hydrogen powered vehicles in the state and 100 or more refueling stations of various sizes.

Maturation Stage – Hydrogen technologies become well established in the stationary power sector, and clean hydrogen production pathways are becoming fully established. Hydrogen powered vehicle ownership spreads more broadly to the general public, and hydrogen fuel becomes available at 10-20% of retail service stations. Under the current ZEV mandate, the minimum number of ZEVs in the State would be 25,000 in the 2012-2014 timeframe and 50,000 in the 2015-2017 timeframe (with up to half battery-powered EVs and the remainder FCVs). Under Title 13 of the California Code of Regulations clean fuel refueling outlets must be provided by major owners of refueling infrastructure in the State once a certain threshold of low-emission vehicles using a particular alternative fuel is reached. This threshold is 20,000 vehicles that all use the same clean fuel, with fleet vehicles discounted by 75% (i.e., each four fleet vehicles would count as one vehicle towards the threshold).[15] During this maturation stage, this regulation would be triggered and this would greatly increase the number of hydrogen refueling locations in California. Once 10% of retail service stations were dispensing hydrogen, then this regulation would reach a "sunset" and any additional growth in the number of refueling locations would be market driven.

Timeline and Milestones: Post-2012 with over 20,000 hydrogen-powered vehicles in California and hydrogen fuel becoming widely available.

Financing Mechanisms for Hydrogen and Renewable Energy Infrastructure Development

The "California Hydrogen Highway Network" Executive Order issued by Gov. Schwarzenegger is controversial partly because of the State's current budget crisis. Given the serious fiscal situation confronting the State, which is likely to persist for at least the next few years, attention must be paid to financing renewable energy development and early hydrogen infrastructure projects in ways that are creative and that do not heavily burden either the State's general fund or its taxpayers.

The potential methods of financing hydrogen infrastructure development, and increasing funding for clean energy system development and deployment more generally, are numerous and have important short and long range implications. These options range from revenue bonds, to measures that would burden the California general fund, to those that would use fines and repayments to the state for the electricity deregulation "market power" settlements, to those that would impose taxes on the current users of the gasoline – just to name a few of the many possibilities.

Another important stimulus for clean energy development will be the $200 million (and perhaps ultimately up to $1.5 billion) "Green Wave" investment program in environmental and energy efficient funds State Treasurer Phil Angelides launched in February of 2004. This program will

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[15] This regulation applies to owners of refueling stations of varying sizes, depending on the number of new clean fuel refueling stations that need to be added each year (based on a formula in the regulation). The largest owners would be required to comply at first, and then smaller owners would be included as the number of clean fuel vehicles grows. "Fleet vehicles" are considered to be vehicles in fleets that contain at least 15 clean fuel vehicles. See CCR Title 13, §2300-2317 for details.

use CalPERS and CalSTRS, the nation's first and third largest pension funds with combined assets of over $270 billion, to invest in funds that simultaneously create financial returns, further the State's economy, and provide environmental benefits. The following is an excerpt from Treasurer Angelides' April 12, 2004 speech to the Commonwealth Club in San Francisco announcing the Green Wave program:[16]

> "I want to say here and now that California should own this industry. Today, 45,000 people in the European Union are employed in wind-power manufacturing alone. And the global market for renewable energy is estimated to reach as much as $1.9 trillion by 2020. California was once a world leader in renewable energy. We need to lead the way once again. California has the scientists, engineers and research institutions to be on the leading edge of environmental technology. It has the manufacturing expertise and skilled workers. It has the culture of entrepreneurship and the tradition of imagining the next new thing, sometimes at the lab bench, sometimes in a garage. It has the venture capital network to fund and nurture start-up companies. It has a citizenry eager to preserve California's environment. Ladies and gentlemen, California should own this industry.
>
> Under the Green Wave initiative, CalPERS and CalSTRS will partner with the private sector to invest venture capital, expansion capital and project financing to spur along clean technology companies in California and across the country. This $500 million commitment—the first $200 million of which was approved last month—will directly create about 10,000 jobs and spawn hundreds of thousands more through the magic of the multiplier effect. And this investment has the potential to send a clear message across the nation: By investing in companies devoted to solving environmental problems, you can get returns, create jobs, bolster the economy and improve the environment."

Other sources of funding for renewable energy, energy efficiency, and hydrogen infrastructure that could be leveraged with Green Wave investment funds, CEC PIER funds, and U.S. DOE renewables, hydrogen, and DG funds include:

- State agency procurement funds for energy and transportation services, potentially coordinated by DGS;
- Partnerships with industry that tie the licensing rights for major oil refinery and electric powerplant construction/expansion projects to significant commitments from the industry applicants to provide funds for renewable energy and hydrogen infrastructure development;
- Revenues from auctions where the rights to dispense hydrogen at the most attractive sites for early hydrogen infrastructure are auctioned off or leased to high bidders.
- Funds from a "public goods charge" on natural gas sales, similar to the PIER program for electricity ratepayer benefits (this natural gas public goods charge R&D program is currently being established by the CPUC);
- Settlement funds from utility bankruptcy proceedings, such as the $16 million "clean energy technology incubator" that PG&E; and
- Settlement funds from legal resolution of disputes with out-of-state power producers in the aftermath of the deregulated electricity market failure.

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[16] See Appendix VI for Treasurer Angelides' full speech to the Commonwealth Club.

With regard to potential tax measures, an increase of $0.005 (one half cent) per gallon in the California state gasoline tax would generate approximately $80 million per year in additional revenue. This would be enough to build 80 $1 million hydrogen stations or 160 $500,000 stations per year, or (much better in our view) to provide for some combination of hydrogen refueling station experiments plus R&D funds for renewable energy and energy efficiency advances more broadly as part of an overall "clean energy science and technology initiative."

6. Conclusions and Recommendations

We feel that efforts to explore and expand the use of hydrogen in California should be part of a larger initiative to develop clean and sustainable energy resources for the State. Such an initiative is critical for both economic development and environmental reasons. We feel that significant continued attention to the use of hydrogen is justified by the tremendous potential that it has as a new energy carrier or "currency," and in particular the potential for hydrogen to become a bridge between renewable energy resources and transportation fuels. However, it is critical that the use of hydrogen be considered as a *means to an end* (or more correctly a set of 'ends') rather than *an end in itself*. We believe that it is only in this way that the public can be assured that the use of hydrogen truly plays an appropriate role in an improved energy system for California.

We are concerned that the very understandable excitement about the potential future promise of the use of hydrogen has caused too much attention in certain areas, and not enough in others. What is lacking is a broader strategy for energy systems where hydrogen takes an appropriate role – rather than expediently "shoe horning" the use of hydrogen into energy systems that are not yet ready and where there is a significant risk of technological lock-in to the "wrong" systems.

Instead, the agenda in our view should be a broad initiative that prioritizes making electricity and providing transportation and energy services with clean and sustainable sources, and then identifies key niches and roles for hydrogen that *improve* the potential performance and economics of those systems. This requires strengthened and coordinated policies for development of renewable and other clean energy sources, continued and enhanced policies for cleaner and more climate-friendly light and heavy-duty vehicles, an emphasis on improving the end-use efficiency of all energy use, and leveraged and coordinated financing and R&D funding strategies. This "integrated strategy" would be a low risk plan because it would first and foremost emphasize the development of clean and sustainable energy resources, and this would provide benefits even if the use of hydrogen continues to be hampered by difficulties in resolving the remaining barriers to its wider use.

California is uniquely positioned to undertake this initiative based on the energy and environmental policy and resource conditions in the state, and its leadership position for clean energy development. Key elements of this expanded clean energy science and technology initiative would include the following:

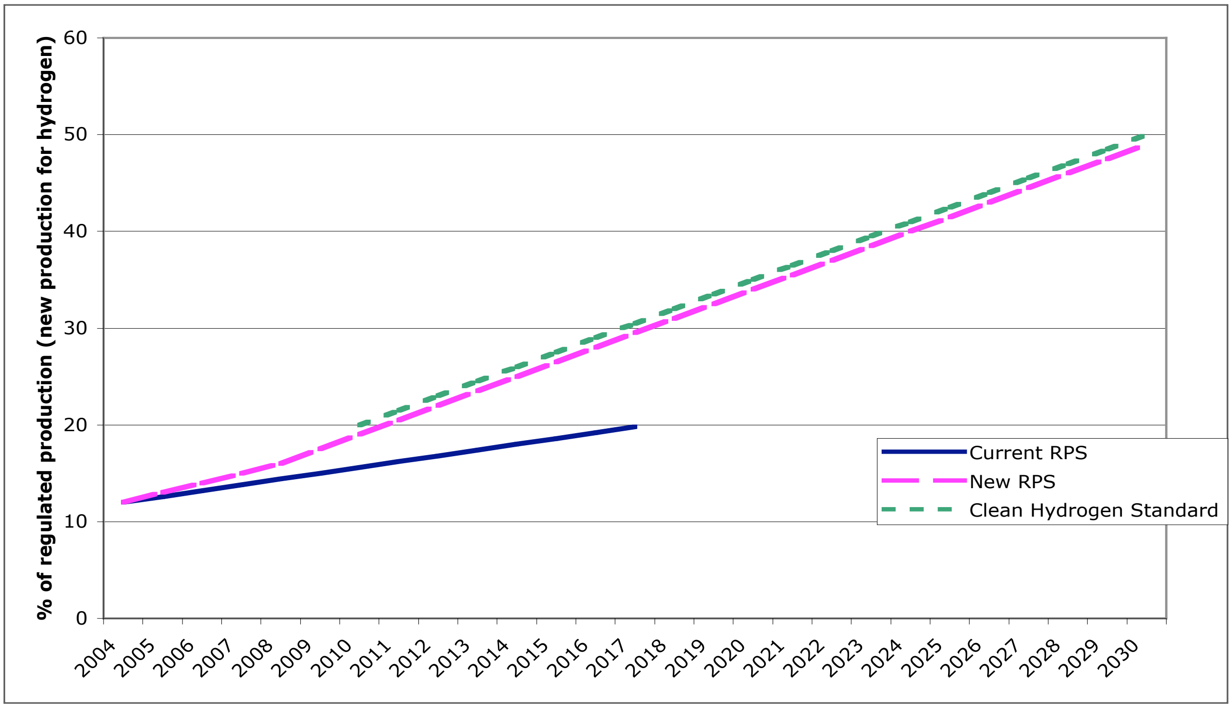
- Collaborative R&D efforts and public/private partnerships to leverage resources for clean energy R&D and deployment, including aggressive pursuit of federal resources;
- A stronger policy context for clean energy in California including: a) acceleration of the State's RPS goals to achieve 20% renewable electricity production by

2010 and 33% by 2020, including compliance by municipal utilities as well as IOUs; b) clear policies for extending the RPS or developing an analogous program to include hydrogen production and provide a set of similarly escalating “clean and renewable” hydrogen production targets; and c) providing additional incentives for new renewable energy capacity associated with the production and use of hydrogen;

- Continued emphasis of CEC PIER program research on clean and sustainable energy technologies, as well as a re-orientation of program priorities toward critical R&D needs for the cleanest technologies and significant funding for hydrogen energy research that is relevant to the electricity sector;
- Expanded efforts for energy-efficiency programs, including demand reduction through end-use efficiency improvements, demand response technologies and programs for the electricity sector, and additional “green building” programs;
- Enhanced pressure to further reduce on-road emissions of criteria pollutants and GHGs from mobile sources, and to reduce consumption of fossil fuels;
- Continued and expanded experimentation with hydrogen technologies for stationary power and transportation applications -- but without taking for granted the potential success of these technologies; and
- Coordination and alignment of major State energy R&D and finance programs, including the CEC PIER program, a new program funded by public goods charges on natural gas sales (currently being established by the CPUC), the Green Wave initiative, technology deployment incentive programs, clean technology “incubators”, and various other financing and incentive programs.

We recommend two key energy policy changes, along with broader increased efforts to increase investment in and R&D for clean energy for California. These policy changes include an accelerated and extended RPS for wholesale electricity sales, and as well a potential “clean hydrogen standard” that would increase clean hydrogen approximately in proportion with the RPS goals. This hydrogen standard would apply to all new hydrogen production and increases in production from or expansions to existing hydrogen facilities. The standard would include a definition of “clean hydrogen” that takes into account the full fuel cycle and includes sustainable feedstocks, low air pollutant emissions, low GHG emissions, and low other environmental impacts (soil and water, etc.). This would stimulate *new* renewable energy development for hydrogen production, advance biofuel-to-hydrogen system development, and assure that California remains on the path to reliance on clean and renewable sources for both electricity and hydrogen. See Figure 13 below for a depiction of these programs relative to the current RPS goals.

Figure 13: Recommended California Renewable Electricity Portfolio Standard (RPS) and Potential Clean Hydrogen Standard Policies



Specifically with regard to continued efforts to explore the use of hydrogen and its role in a clean energy future for California, we recommend that the State consider pursuit of these strategies:

1) Build on existing projects, programs, and energy and transportation infrastructure and pursue aggressive but incremental steps as the vehicle market develops;

2) Use public/private partnerships to leverage resources and combine expertise;

3) Explore the integration of hydrogen infrastructure development with distributed electrical power generation (e.g. hydrogen "energy stations") and innovative mobility systems (e.g., shared-use vehicle services facilitated by electronic and wireless reservation and communication technologies);

4) Focus initial hydrogen infrastructure developments on prioritized "key corridors" and in a coordinated fashion, and include experimentation with innovative low-cost hydrogen distribution options (e.g. mobile dispensing platforms and integration with activities with large fleet and retail companies);

5) Emphasize and lay out a clear plan for using California's domestic resources to produce hydrogen cleanly, and increasingly from renewable sources, and prioritize R&D on electrolyzer and biomass-to-hydrogen systems;

6) Experiment with hydrogen for off-road uses including forklifts and other vehicles operating inside buildings, construction site applications, and in maritime and agricultural settings;

7) Demonstrate hydrogen safety and reliability through development of codes and standards for hydrogen energy systems;

8) Use State action to encourage all hydrogen refueling stations, including those owned by public and private fleets, to be available to the public (wherever practical); and
9) Use existing and new mechanisms, such as the partnership among Caltrans, ARB, and CEC, to coordinate State agency activities as appropriate.

In conclusion, continued development and deployment of clean energy technologies is critical to California's future economic growth, human health and welfare, and environmental quality. Hydrogen technologies represent one important part of this future, but *it is essential that efforts to promote hydrogen as an energy carrier occur in the context of a broader clean energy and energy efficiency strategy for the State*. This is the case because the costs of transitioning to the use of hydrogen as an energy carrier beyond niche markets are unlikely to be justifiable unless the benefits of doing so are maximized by producing hydrogen cleanly and sustainably. Continuing to raise the bar for conventional technologies may ultimately favor hydrogen-based technologies, and emphasizing clean electricity production is important both for direct benefits to the electricity sector and because much of the energy needed for hydrogen production and/or distribution will be in the form of electricity. Even if hydrogen is not produced electrolytically, compression or liquefaction and distribution of hydrogen entails considerable electricity input.

It is therefore necessary to place efforts to expand the use of hydrogen in the broader context of an overall clean energy strategy that emphasizes renewable energy, energy efficiency, and better operation of existing electrical and other fuel distribution infrastructures. This strategy would enhance the benefits that hydrogen can offer if the "Hydrogen Economy" does in fact develop rapidly, but it also would provide clear benefits to the State even if it does not.

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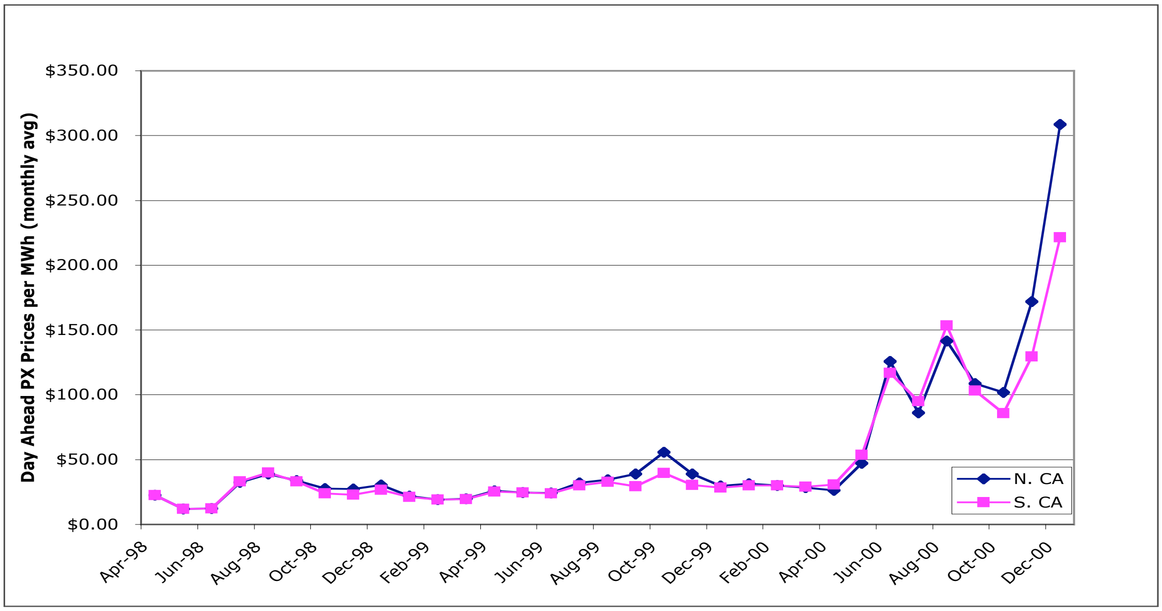
Appendix I:

A Brief Summary of California's Recent Experience with Electricity Market Deregulation

California moved aggressively into a deregulated market structure with the passage of the electricity market "deregulation bill" AB 1890 in 1996. The bill passed the California Legislature under the declaration that "the restructuring of the [State] electricity industry has been driven by changes in federal law intended to increase competition in the provision of electricity" (California Assembly Bill 1890, Section 1[a]). The bill was quickly signed by Gov. Pete Wilson amid widespread hopes that competition among electricity suppliers would reduce wholesale electricity costs and ultimately retail prices, as set by the California Public Utility Commission and various municipal utility district boards. Among other provisions including those related to recovery of utility "stranded costs" and funding of public purpose and environmental programs, the landmark AB 1890 required investor owned utilities (IOUs) to divest themselves of most power generating assets, created competitive wholesale markets for electricity and utility grid ancillary services, and placed the responsibility for operating the State's utility grid with the California Independent System Operator (CAISO) and an associated oversight board.

However, due to the confluence of several key factors including increases in natural gas prices, drought and lower than normal hydropower resources in the Pacific Northwest, and – most importantly -- an electricity market design that allowed for market power by electricity producers, electricity prices increased rapidly in much of California after about a year of the deregulated regime. Gov. Gray Davis appealed to the Federal Electricity Regulatory Commission (FERC) to lower wholesale price caps to restrain electricity costs as this was occurring but, with leadership believing strongly in the free market philosophy, FERC was conservative in its actions and did not help stem the crisis. Figure 2 shows the wholesale power prices observed under the deregulated market from its start in 1998 through 2000 when the market effectively started to spin out of control.

Figure 2: California Day-Ahead Power Exchange Wholesale Electricity Prices -- 4/98-12/00



Source: CEC, 2002

Thus, the deregulated electricity market in California lasted for less than two years before re-regulation measures were necessary to lower wholesale power prices. While some of the increase in electricity cost was legitimately due to external circumstances, overcharges due to market power of as much as $5.5 billion during the period from 1998 through 2000 have been alleged (Reiterman and Brooks, 2001). With the design of the power market, the majority of these excess charges could not be passed directly on to ratepayers (except in the service territory of San Diego Gas and Electric, where consumers were exposed to dramatically increased retail prices in late 2000). This situation led to declaration of Chapter 11 bankruptcy by PG&E, and narrow avoidance of a similar declaration by Southern California Edison (SCE), along with the need for the State to purchase power in long-term contracts at relative expensive rates. This electricity crisis has contributed to the fiscal problems currently confronting the State and, with the passage of a $15 billion revenue bond act in March of 2004 (partly to help cover these costs), the impacts of the ill-fated power market deregulation in California will be felt for many years to come.

Appendix II:

California Hydrogen and Fuel Cell Organizations

Hydrogen and Fuel Cell Companies and Research Organizations In California:

- Advance: Solar, Hydro, Wind Power Company (Calpella)
- Advanced Material Sciences, Inc. (Pasadena)
- AeroVironment, Inc. (Monrovia)
- AESC, Inc. (Carlsbad)
- Air Products and Chemicals, Inc. (Concord)
- Alternative Energy Systems Consulting, Inc. (Carlsbad)
- American Association for Fuel Cells (Daly City)
- AMREL/American Reliance (Arcadia)
- Anuvu Incorporated (Sacramento)
- ARCADIS Geraghty & Miller, Inc. (Fullerton)
- Asia Pacific Fuel Cell Technologies, Ltd. (Anaheim)
- BAT International (Chula Vista)
- Bechtel Corporation (San Francisco)
- C2i, Ltd. (Aptos)
- California Air Resources Board (Sacramento)
- California Energy Commission (Sacramento)
- California Fuel Cell Partnership (West Sacramento)
- California Hydrogen Business Council (Los Alamitos)
- California Stationary Fuel Cell Collaborative (Sacramento)
- Catalytica Energy Systems (Mountain View)
- Circle Seal Controls Division, Circor International (Corona)
- City of Chula Vista (Chula Vista)
- Coval Partners (Desert Hot Spring)
- Down Stream Systems, Inc. (Folsom)
- EHG Technology, LLC (Los Angeles)
- Electric Power Research Institute (Palo Alto)
- Electric Vehicle Information Services (Moraga)
- Enova Systems (Torrance)
- Fluor Daniel (Aliso Viejo)
- Fuel Cell Buyers Consortium (Los Angeles)
- Fuel Cell Infrastructure, Inc. (Carmichael)
- FuelSell Technologies (San Francisco)
- GE EER Corporation (Irvine)
- GE Energy & Environmental Research Corporation (Irvine)
- General Atomics (San Diego)
- General Motors - Advanced Technology Vehicles (Torrance)
- Glacier Bay, Inc. (Oakland)
- Global Fuel Cell Corporation (Chula Vista)
- H2 Solutions Inc. (Hollister)
- H2 ECOnomy (Glendale)
- Harvest Energy Technology, Inc. (Sun Valley)
- Honda R&D Americas, Inc. (Torrance)
- Honeywell (Torrance)
- Humboldt State University - Schatz Energy Research Center (Arcata)
- Hydrogen Ventures, LLC (Santa Monica)

- HyGen Industries, LLC (Marina Del Rey)
- IMPCO Technologies, Inc. (Irvine)
- Independent Energy Partners (Englewood)
- ISE Research Corporation (San Diego)
- Jet Propulsion Laboratory (Pasadena)
- John B. O'Sullivan, Consultant (Mountain View)
- John Nimmons & Associates, Inc. (Mill Valley)
- L-3 Communications/Power Paragon, Inc. (Anaheim)
- Lawrence Berkeley National Laboratory (Berkeley)
- Lawrence Livermore National Laboratory (Livermore)
- Mazda R&D of North America, Inc. (Irvine)
- Mechanology, LLC (Palo Alto)
- Merit Academy (Soquel)
- Meruit, Inc. (Santa Monica)
- Metallic Power, Inc. (Carlsbad)
- National Fuel Cell Education Program (Tustin)
- National Fuel Cell Research Center (Irvine)
- Nexant, Inc. (San Fransisco)
- Panasonic Technologies, Inc. (Cupertino)
- PFG Energy Capital (Pasadena)
- Polyfuel, Inc. (Menlo Park)
- Power Correction Systems, Inc. (Los Angeles)
- Power Point International (San Jose)
- Powerzinc Electric, Inc. (City of Industry)
- QUANTUM Fuel Systems Technologies Worldwide, Inc. (Irvine)
- RealEnergy, Inc. (Sacramento)
- RIX Industries (Benicia)
- Sacramento Municipal Utility District (Sacramento)
- Sandia National Laboratory (Livermore)
- San Diego Miramar College (San Diego)
- Saratoga Technology Associates (Saratoga)
- SFA Pacific, Inc. (Menlo Park)
- SolarEn International Corporation (Glendale)
- South Coast Air Quality Management District (Diamond Bar)
- Southern California Edison (Rosemead)
- Southern California Gas (Los Angeles)
- Stuart Energy USA (Van Nuys)
- SunLine Services Group (Thousand Palms)
- Symyx Technologies, Inc. (Santa Clara)
- Technip USA Corporation (San Dimas)
- Telaire (Goleta)
- Toray Carbon Fibers America (Santa Ana)
- University of California, Berkeley – Energy and Resources Group (Berkeley)
- University of California, Davis – Institute of Transportation Studies (Davis)
- University of California, Irvine – National Fuel Cell Research Center (Irvine)
- University of California, Riverside – Bourns College of Engineering (Riverside)
- Valley Environmental Associates (Yorba Linda)
- W.J. Schafer Associates (Livermore)
- Wesgo Metals (San Carlos)
- West-Start/CALSTART (Pasadena)

Appendix III:

Hydrogen Production Cost and Delivered Cost Estimates

Table A-II: Summary of Recent Hydrogen Production Cost Estimates

Production Method	Scale of Production	Production Cost (HHV basis)	Key Details and Market Status	Source
Natural Gas				
Steam Methane Reforming	239 kg/day 884 kg/day 2,390 kg/day *Small-Medium*	\$5.39/kg (\$37.96/GJ) \$2.76/kg (\$19.44/GJ) \$1.92/kg (\$13.52/GJ)	*Near Term*	Ogden et al., 1996
Steam Methane Reforming	625 kg/day *Small*	\$2.60/kg (\$18.31/GJ) Single station \$1.93/kg (\$13.59/GJ) 100 stations \$1.68/kg (\$11.83/GJ) 10,000 stations	NG at \$6.16/GJ "Energy station" with 100 kW of power sold to grid *Near Term*	Thomas et al., 2001
Steam Methane Reforming	609,000 kg/day (1 GW_{H2}) *Large*	\$0.78/kg (\$5.50/GJ) (NG@\$3.00/GJ) \$0.94/kg (\$6.60/GJ) (NG@\$3.90/GJ) \$0.97/kg (\$6.85/GJ) (NG@\$4.10/GJ)	NG at \$3.00-4.10/GJ 81% SMR efficiency *Commercial*	Williams, 2002
Steam Methane Reforming	609,000 kg/day (1 GW_{H2}) *Large*	\$1.02/kg (\$7.20/GJ)	NG at \$3/GJ 81% SMR efficiency 85% of CO_2 emissions captured *Research and Devt.*	Williams, 2002
Steam Methane Reforming	470 kg/day *Small*	\$4.40/kg (\$30.99/GJ)	NG at \$5.25/GJ Small-scale prod. *Near Term*	Simbeck and Chang, 2002
Steam Methane Reforming	609,000 kg/day (1 GW_{H2}) *Large*	\$0.90/kg (\$6.33/GJ)	NG at \$3.67/GJ CO_2 vented *Commercial*	Ogden et al., 2004
Steam Methane Reforming	609,000 kg/day (1 GW_{H2}) *Large*	\$1.14/kg (\$8.04/GJ)	NG at \$3.67/GJ 85% of CO_2 emissions captured *Research and Devt.*	Ogden et al., 2004
Steam Methane Reforming	480 kg/day *Small*	\$3.51/kg (\$24.75/GJ) Current \$2.33/kg (\$16.43/GJ) Future	NG at \$6.16/GJ SMR efficiency: 60% (current) 70% (future) *Near Term/Future*	NAS/NRC, 2004
Steam Methane Reforming	24,000 kg/day *Medium*	\$1.38/kg (\$9.73/GJ) Current \$1.21/kg (\$8.53/GJ) Future	NG at \$4.27/GJ SMR efficiency: 72% (current) 77% (future) *Near Term/Future*	NAS/NRC, 2004
Steam Methane Reforming	24,000 kg/day *Medium*	\$1.76/kg (\$12.41/GJ) Current \$1.55/kg (\$10.93/GJ) Future	NG at \$4.27/GJ CO_2 sequestered SMR efficiency: 69% (current) 72% (future) *Near Term/Future*	NAS/NRC, 2004

Steam Methane Reforming	1.1 million kg/day *Large*	$1.03/kg ($7.26/GJ) Current $0.92/kg ($6.49/GJ) Future	NG at $4.27/GJ SMR efficiency: 76.2% (current) 80% (future) *Near Term/Future*	NAS/NRC, 2004
Steam Methane Reforming	1.1 million kg/day *Large*	$1.31/kg ($9.24/GJ) Current $1.10/kg ($7.76/GJ) Future	NG at $4.27/GJ CO_2 sequestered SMR efficiency: 72% (current) 78% (future) *Near Term/Future*	NAS/NRC, 2004
Natural Gas/Solar Assist				
Concentrating Solar NG Reactor	250 kg/day 450 kg/day 748 kg/day *Small*	$2.56/kg ($18/GJ) (8,750 m^2 heliostat) $2.84/kg ($20/GJ) (4.375 m^2 heliostat) $3.41/kg ($24/GJ) (2,188 m^2 heliostat)	NG at $3.72/GJ *Research and Devt.*	Spath and Amos, 2002
Coal				
Oxygen-blown Gasification	313,090 kg/day *Large*	$0.92/kg ($6.48/GJ)	CO_2 vented 63.7% effic. (HHV) 20.4 MW net power *Commercial*	Gray and Tomlinson, 2002
Oxygen-blown Gasification	284,410 kg/day *Large*	$1.10/kg ($7.75/GJ)	CO_2 sequestered for $10/ton of carbon 59.0% effic. (HHV) 26.9 MW net power *Research and Devt.*	Gray and Tomlinson, 2002
Advanced Gasification With Hot Gas Cleanup	377,620 kg/day *Large*	$0.79/kg ($5.56/GJ)	CO_2 sequestered for $10/ton of carbon 75.5% effic. (HHV) 25.0 MW net power *Research and Devt.*	Gray and Tomlinson, 2002
Oxygen-blown Gasification	150,000 kg/day *Large*	1.62/kg ($11.41/GJ)	Coal at $29.11/ton CO_2 vented *Commercial*	Simbeck and Chang, 2002
Oxygen-blown Gasification	609,000 kg/day (1 GW_{H2}) *Large*	$0.89/kg ($6.25/GJ)	Coal at $1.17/GJ CO_2 vented *Commercial*	Williams, 2002
Oxygen-blown Gasification	1.2 million kg/day *Large*	$0.96/kg ($6.77/GJ) Current $0.71/kg ($5.01/GJ) Future	Coal at $1.16/GJ CO_2 vented *Commercial/Future*	NAS/NRC, 2004
Oxygen-blown Gasification	1.2 million kg/day *Large*	$1.19/kg ($8.39/GJ) Current $0.92/kg ($6.49/GJ) Future	Coal at $1.16/GJ CO_2 sequestered *Commercial/Future*	NAS/NRC, 2004
Oxygen-blown Gasification	609,000 kg/day (1 GW_{H2}) *Large*	$0.81/kg ($5.69/GJ)	CO_2 vented *Commercial*	Ogden et al., 2004
Oxygen-blown Gasification	609,000 kg/day (1 GW_{H2}) *Large*	$1.05/kg ($7.36/GJ)	CO_2 sequestered *Research and Devt.*	Ogden et al., 2004

Petroleum Coke				
Gasification	150,000 kg/day *Large*	$1.35/kg ($9.51/GJ)	CO_2 vented 21.0 MW net power *Near Commercial.*	Simbeck and Chang, 2002
Nuclear				
SI-MHR	n.s. *Large*	$0.95-1.60/kg ($6.69-11.28/GJ)	5-15% interest rate *Research and Development*	Brown et al., 2002
SI-MHR	n.s. *Large*	$1.30/kg ($9.15/GJ)	$686/kW cap. cost 10% interest rate *Research and Devt.*	Henderson, 2002
Nuclear Thermal of Water	1.2 million kg/day *Large*	$1.63/kg ($11.50/GJ) Future	$2.5 million plant capital cost *R&D/Future*	NAS/NRC, 2004
Biomass				
Battelle Gasifier	147,900 kg/day *Large*	$0.84/kg ($5.9/GJ) ($2/GJ biomass, 6% DR) $1.21/kg ($8.5/GJ) (($4/GJ biomass, 6% DR) $0.97/kg ($6.8/GJ) (($2/GJ biomass, 12% DR) $1.33/kg ($9.4/GJ) (($4/GJ biomass, 12% DR)	Biomass at $2-4/GJ 70% thermal effic. *Demonstration*	Ogden and Nitsch, 1993
Pyrolysis	Not specified	$1.09/kg ($7.70/GJ)	Phenolic co-product sold for $0.44/kg *Commercial*	French et al., 2000
Battelle/FERCO Gasifier	22,737 kg/day *Medium*	$1.12/kg ($7.90/GJ) *$2.43/kg ($17.08/GJ)* *With 15% after tax IRR*	$54 mill. cap. Cost *Demonstration*	Spath et al, 2000
Battelle/FERCO Gasifier	75,790 kg/day *Medium*	$1.25/kg ($8.81/GJ) *$2.19/kg ($15.39/GJ)* *With 15% after tax IRR*	$129 mill. cap. Cost *Demonstration*	Spath et al, 2000
Battelle/FERCO Gasifier	113,685 kg/day *Large*	$1.19/kg ($8.41/GJ) *$2.03/kg ($14.29/GJ)* *With 15% after tax IRR*	$172 mill. cap. Cost *Demonstration*	Spath et al, 2000
IGT Gasifier	22,737 kg/day *Medium*	$1.19/kg ($8.40/GJ) *$2.93/kg ($20.64/GJ)* *With 15% after tax IRR*	$72 mill. cap. cost *Demonstration*	Spath et al, 2000
IGT Gasifier	75,790 kg/day *Medium*	$1.27/kg ($8.95/GJ) *$2.50/kg ($17.61/GJ)* *With 15% after tax IRR*	$169 mill. cap. cost *Demonstration*	Spath et al, 2000
IGT Gasifier	113,685 kg/day *Large*	$1.20/kg ($8.48/GJ) *$2.29/kg ($16.16/GJ)* *With 15% after tax IRR*	$227 mill. cap. cost *Demonstration*	Spath et al, 2000
Pyrolysis	22,737 kg/day *Medium*	$0.93/kg ($6.57/GJ) *$1.45/kg ($10.24/GJ)* *With 15% after tax IRR*	$19 mill. cap. cost *Commercial*	Spath et al, 2000
Pyrolysis	75,790 kg/day *Medium*	$0.75/kg ($5.30/GJ) *$1.23/kg ($8.69/GJ)* *With 15% after tax IRR*	$59 mill. cap cost *Commercial*	Spath et al, 2000
Gasifier	24,000 kg/day *Medium*	$4.63/kg ($32.65/GJ) Current $2.21/kg ($15.59/GJ) Future	Biomass at: $2.85/GJ (current) $1.91/GJ (future) CO_2 vented *Near Term/Future*	NAS/NRC, 2004

Gasifier	24,000 kg/day *Medium*	$5.08/kg ($35.83/GJ) Current $2.53/kg ($17.84/GJ) Future	Biomass at: $2.85/GJ (current) $1.91/GJ (future) CO_2 sequestered *Near Term/Future*	NAS/NRC, 2004
Wind				
Electrolysis	1,267 kg/day *Small-Medium*	$1.56/kg ($11.0/GJ) (6% DR) $2.27/kg ($16.0/GJ) (12% DR)	Excellent sites (630 W/m^2) *Near Commercial*	Ogden and Nitsch, 1993
Electrolysis	1,267 kg/day *Small-Medium*	$2.41/kg ($17.0/GJ) (6% DR) $3.55/kg ($25.0/GJ) (12% DR)	Good sites (350 W/m^2) *Near Commercial*	Ogden and Nitsch, 1993
Electrolysis	n.s. 10 MW of wind power *Small-Medium*	$3.90/kg ($27.5/GJ) Year 2000 $3.00/kg ($21.1/GJ) Year 2010	Grid-Tied Wind power: $900/kW (2000) $700/kW (2010)	Mann et al., 1998
Electrolysis	n.s. 10 MW of wind power *Small-Medium*	$7.10/kg ($50.0/GJ) Year 2000 $4.00/kg ($28.2/GJ) Year 2010	Stand-Alone Wind power: $900/kW (2000) $700/kW (2010)	Mann et al., 1998
Electrolysis	n.s. *Small-Medium*	$1.86-2.63/kg ($13.00-18.50/GJ) *$3.20-3.98/kg* *($22.50-28.00/GJ)* *w/15% IRR, 37% taxation*	Grid-Tied Various Design and Econ. Assumption	Padro, 2002
Electrolysis	n.s. *Small*	$1.14/kg ($8.00/GJ) *$4.33/kg ($30.50/GJ)* *w/15% IRR, 37% taxation*	Stand-Alone	Padro, 2002
Electrolysis	1,600 kg/day Current 1,200 kg/day Future *Small-Medium*	$10.69/kg ($75.39/GJ) Current $2.86/kg ($20.17/GJ) Future	Stand-Alone *Near Term/Future*	NAS/NRC, 2004
Electrolysis	480 kg/day *Small*	$6.81/kg ($48.03/GJ) Current $3.50/kg ($24.68/GJ) Future	Grid-Tied *Near Term/Future*	NAS/NRC, 2004
Solar				
PV Electrolysis	1,267 kg/day *Small-Medium*	$6.39-14.34/kg ($45-101/GJ) (6% DR) *$10.37-23.71/kg* *($73-167/GJ) (12% DR)*	ca. 1991 Southwest U.S. *Near Commercial*	Ogden and Nitsch, 1993
PV Electrolysis	1,267 kg/day *Small-Medium*	$1.42-2.27/kg ($10-16/GJ) (6% DR) *$2.13-3.55/kg ($15-25/GJ)* *(12% DR)*	Future Projection Southwest U.S. *Near Commercial*	Ogden and Nitsch, 1993
PV Electrolysis	10 MWe *Small-Medium*	$25.84/kg ($182/GJ) $12.21/kg ($86/GJ) $6.39/kg ($45/GJ)	PV at $5,000/kW PV at $2,000/kW PV at $750/kW *Near Commercial*	Glatzmaier et al., 1998
Solar Dish-Stirling Electrolysis	10 MWe *Small-Medium*	$11.64/kg ($82/GJ) $10.79/kg ($76/GJ)	Year 2010 Year 2020 *Demonstration*	Glatzmaier et al., 1998

Solar Power-Tower Electrolysis	200 MWe *Medium*	$7.10/kg ($50/GJ) $5.96/kg ($42/GJ)	Year 2010 Year 2020 *Demonstration*	Glatzmaier et al., 1998
High-Temperature Electrolysis	200 MWe *Medium*	$5.68-6.25/kg ($40-44/GJ) $7.67-11.42/kg ($54-79/GJ)	$500/kW electrolyzer $2,000/kW electrolyzer *Research and Devt.*	Glatzmaier et al., 1998
PV Electrolysis	n.s. 10 MW of solar power *Small-Medium*	$7.40/kg ($52.1/GJ) Year 2000 $4.50/kg ($37.1/GJ) Year 2010	Grid-Tied Solar power: $3,133/kW (2000) $12,662/kW (2010) *Near Term/Future*	Mann et al., 1998
PV Electrolysis	n.s. 10 MW of solar power *Small-Medium*	$17.60/kg ($124.0/GJ) Year 2000 $7.50/kg ($52.8/GJ) Year 2010	Stand-Alone Solar power: $3,133/kW (2000) $12,662/kW (2010) *Near Term/Future*	Mann et al., 1998
PV Electrolysis	n.s. *Small-Medium*	$2.13-2.91/kg ($15.00-20.50/GJ) *$4.83-5.54/kg* *($34.00-39.00/GJ)* *w/15% IRR, 37% taxation*	Grid-Tied Various Design and Econ. Assumption *Future*	Padro, 2002
PV Electrolysis	n.s. *Small*	$1.78/kg ($12.50/GJ) *$8.24/kg ($58.00/GJ)* *w/15% IRR, 37% taxation*	Stand Alone *Future*	Padro, 2002
PV Electrolysis	2,400 kg/day *Small-Medium*	$28.19/kg ($198.81/GJ) Current $6.18/kg ($43.58/GJ) Future	Stand-Alone *Near Term/Future*	NAS/NRC, 2004
PV Electrolysis	480 kg/day *Small*	$9.71/kg ($68.48/GJ) Current $4.37/kg ($30.82/GJ) Future	Grid-Tied *Near Term/Future*	NAS/NRC, 2004
Grid Power				
Electrolysis	24,000 kg/day *Medium*	$4.70/kg ($33.15/GJ) Current $2.30/kg ($16.22/GJ) Future	Electricity at $0.045/kWh *Near Term/Future*	NAS/NRC, 2004
Electrolysis	480 kg/day *Small*	$6.58/kg ($46.41/GJ) Current $3.93/kg ($27.72/GJ) Future	Electricity at $0.07/kWh *Near Term/Future*	NAS/NRC, 2004
Solar Photo-Electrochemical				
PEC Water Splitting	n.s. *Variable*	$2.60/kg ($17.50/GJ) *$11.00/kg ($77.50/GJ)* *w/15% IRR, 37% taxation*	Year 2010 Estimate *Research and Devt.*	Padro, 2002
PEC Water Splitting	n.s. *Variable*	$1.21/kg ($8.50/GJ) *$5.11/kg ($36.00/GJ)* *w/15% IRR, 37% taxation*	Year 2020 Estimate *Research and Devt.*	Padro, 2002

Notes: Production costs are on HHV basis unless otherwise specified. For delivered hydrogen cost estimates, see Table A-2. DR = discount rate (see list of acronyms at front of report for other abbreviations).

Table A-III: Summary of Recent Delivered Hydrogen Cost Estimates

Production Method	**Scale of Production**	**Delivered H_2 Cost (HHV basis)**	**Key Details and Market Status**	**Source**
Natural Gas				
Steam Methane Reforming	2,455 kg/day (2.7 tons/day)	$3.57/kg ($25.14/GJ)\	Distributed production	Moore and Raman, 1998
Steam Methane Reforming	24,550 kg/day (27 tons/day)	$3.35/kg ($23.59/GJ)	Central production Liquid H_2 delivery	Moore and Raman, 1998
Steam Methane Reforming	24,550 kg/day (27 tons day)	$2.91/kg ($20.49/GJ)	Central production Pipeline H_2 delivery	Moore and Raman, 1998
Steam Methane Reforming	Conv. SMR Advanced SMR 2,390 kg/day	$1.92/kg ($13.54/GJ) $2.76/kg ($19.46/GJ)	Distributed production	Ogden et al., 1998
Steam Methane Reforming	High demand Low demand 239,000 kg/day	$1.49/kg ($10.51/GJ) $1.93/kg ($13.61/GJ)	Central production Pipeline delivery	Ogden et al., 1998
Steam Methane Reforming	470 kg/day	$4.40/kg ($30.99/GJ)	Distributed production High pressure storage	Simbeck and Chang, 2002
Steam Methane Reforming	150,000 kg/day	$3.66/kg ($25.77/GJ)	Central production Liquid H_2 delivery	Simbeck and Chang, 2002
Steam Methane Reforming	150,000 kg/day	$5.00/kg ($35.21/GJ)	Central production Pipeline delivery	Simbeck and Chang, 2002
Steam Methane Reforming	150,000 kg/day	$4.39/kg ($30.92/GJ)	Central production Tube trailer delivery	Simbeck and Chang, 2002
Steam Methane Reforming	480 kg/day	$3.51/kg ($24.75/GJ) *Current* $2.33/kg ($16.43/GJ) *Future*	Distributed production High pressure storage	NAS/NRC, 2004
Steam Methane Reforming	24,000 kg/day	$3.81/kg ($26.87/GJ) *Current* $2.62/kg ($18.48/GJ) *Future*	Central production Tanker truck delivery (liquid H_2)	NAS/NRC, 2004
Steam Methane Reforming	24,000 kg/day	$4.18/kg ($29.48/GJ) *Current* $2.95/kg ($20.81/GJ) *Future*	Central production with CO_2 sequestered Tanker truck delivery (liquid H_2)	NAS/NRC, 2004
Steam Methane Reforming	1.1 million kg/day	$1.98/kg ($13.96/GJ) *Current* $1.61/kg ($11.35/GJ) *Future*	Central production Pipeline delivery	NAS/NRC, 2004
Steam Methane Reforming	1.2 million kg/day	$2.26/kg ($15.94/GJ) *Current* $1.80/kg ($12.69/GJ) *Future*	Central production with CO_2 sequestered Pipeline delivery	NAS/NRC, 2004
Coal				
Oxygen-blown Gasification	609,000 kg/day (1 GW_{H2})	$2.21/kg ($15.57/GJ)	Central production CO_2 vented	Ogden et al., 2004
Oxygen-blown Gasification	609,000 kg/day (1 GW_{H2})	$2.45/kg ($17.24/GJ)	Central production CO_2 sequestered	Ogden et al., 2004
Gasification	150,000 kg/day	$4.51/kg ($31.76/GJ)	Central production Liquid H_2 delivery	Simbeck and Chang, 2002

Gasification	150,000 kg/day	$5.62/kg ($39.58/GJ)	Central production Pipeline delivery	Simbeck and Chang, 2002
Gasification	150,000 kg/day	$5.18/kg ($36.48/GJ)	Central production Tube trailer delivery	Simbeck and Chang, 2002
Gasification	1.2 million kg/day	$1.91/kg ($13.47/GJ) *Current* $1.40/kg ($9.87/GJ) *Future*	Central production Pipeline delivery	NAS/NRC, 2004
Gasification	1.2 million kg/day	$2.15/kg ($15.16/GJ) *Current* $1.61/kg ($11.35/GJ) *Future*	Central production Pipeline delivery With CO_2 sequestered	NAS/NRC, 2004
Petroleum Coke				
Gasification	150,000 kg/day	$5.35/kg ($37.68/GJ)	Central production Pipeline delivery	Simbeck and Chang, 2002
Nuclear				
Nuclear Thermal Conversion of Water	1.2 million kg/day	$2.33/kg ($16.43/GJ) *Future*	Central production Pipeline delivery	NAS/NRC, 2004
Wind				
Electrolysis	n.s. (10 MWp)	$3.17/kg ($22.3/GJ) *(6% DR)* $4.32/kg ($30.4/GJ) *(12% DR)*	Future projection Demonstration Scale	Ogden and Nitsch, 1993
Electrolysis	n.s. (750 MWp)	$3.42/kg ($24.1/GJ) *(6% DR)* $4.50/kg ($31.7/GJ) *(12% DR)*	Future projection City supply scale	Ogden and Nitsch, 1993
Electrolysis	1,600 kg/day Current 1,200 kg/day Future	$10.69/kg ($75.39/GJ) *Current* $2.86/kg ($20.17/GJ) *Future*	Distributed production Stand-Alone	NAS/NRC, 2004
Electrolysis	480 kg/day	$6.81/kg ($48.03/GJ) *Current* $3.50/kg ($24.68/GJ) *Future*	Distributed production Grid-Tied	NAS/NRC, 2004
Solar				
PV Electrolysis	n.s. (10 MWp)	$2.26-3.14/kg ($15.9-22.1/GJ) *(6% DR)* $3.12-4.59/kg ($22.0-32.3/GJ) *(12% DR)*	Future projection Southwest U.S. Demonstration Scale	Ogden and Nitsch, 1993
PV Electrolysis	n.s. (750 MWp)	$2.50-3.38/kg ($17.6-23.8/GJ) *(6% DR)* $3.32-4.77/kg ($23.4-33.6/GJ) *(12% DR)*	Future projection Southwest U.S. City supply scale	Ogden and Nitsch, 1993
PV Electrolysis	2,400 kg/day	$28.19/kg ($198.81/GJ) *Current* $6.18/kg ($43.58/GJ) *Future*	Distributed production Stand-Alone	NAS/NRC, 2004
PV Electrolysis	480 kg/day	$9.71/kg ($68.48/GJ) *Current* $4.37/kg ($30.82/GJ) *Future*	Distributed production Grid-Tied	NAS/NRC, 2004
Biomass				
Battelle/FERCO Gasifier	22,737 kg/day	$1.59/kg ($11.22/GJ) *$2.90/kg ($20.40/GJ)* *With 15% after tax IRR*	Central production Pipeline delivery (10 miles)[a]	Spath et al, 2000

Battelle/FERCO Gasifier	75,790 kg/day	$1.50/kg ($10.59/GJ) *$2.44/kg ($17.17/GJ)* *With 15% after tax IRR*	Central production Pipeline delivery (10 miles)[a]	Spath et al, 2000
Battelle/FERCO Gasifier	113,685 kg/day	$1.41/kg ($9.94/GJ) *$2.25/kg ($15.82/GJ)* *With 15% after tax IRR*	Central production Pipeline delivery (10 miles)[a]	Spath et al, 2000
IGT Gasifier	22,737 kg/day	$1.66/kg ($11.72/GJ) *$3.40/kg ($23.96/GJ)* *With 15% after tax IRR*	Central production Pipeline delivery (10 miles)[a]	Spath et al, 2000
IGT Gasifier	75,790 kg/day	$1.52/kg ($10.73/GJ) *$2.75/kg ($19.39/GJ)* *With 15% after tax IRR*	Central production Pipeline delivery (10 miles)[a]	Spath et al, 2000
IGT Gasifier	113,685 kg/day	$1.42/kg ($10.01/GJ) *$2.51/kg ($17.69/GJ)* *With 15% after tax IRR*	Central production Pipeline delivery (10 miles)[a]	Spath et al, 2000
Pyrolysis	22,737 kg/day	$1.40/kg ($9.89/GJ) *$1.93/kg ($13.56/GJ)* *With 15% after tax IRR*	Central production Pipeline delivery (10 miles)[a]	Spath et al, 2000
Pyrolysis	75,790 kg/day	$1.01/kg ($7.08/GJ) *$1.49/kg ($10.47/GJ)* *With 15% after tax IRR*	Central production Pipeline delivery (10 miles)[a]	Spath et al, 2000
Gasification	150,000 kg/day	$4.98/kg ($35.07/GJ)	Central production Liquid H_2 delivery	Simbeck and Chang, 2002
Gasification	150,000 kg/day	$6.29/kg ($44.30/GJ)	Central production Pipeline delivery	Simbeck and Chang, 2002
Gasification	150,000 kg/day	$5.77/kg ($40.63/GJ)	Central production Tube trailer delivery	Simbeck and Chang, 2002
Gasification	24,000 kg/day	$7.04/kg ($49.65/GJ) *Current* $3.62/kg ($25.53/GJ) *Future*	Central production Tanker truck delivery (liquid H_2)	NAS/NRC, 2004
Gasification	24,000 kg/day	$7.50/kg ($52.89/GJ) *Current* $3.89/kg ($27.43/GJ) *Future*	Central production Tanker truck delivery (liquid H_2) CO_2 sequestered	NAS/NRC, 2004
Grid Power				
Electrolysis	480 kg/day	$6.58/kg ($46.41/GJ) *Current* $3.93/kg ($27.72/GJ) *Future*	Distributed production	NAS/NRC, 2004
Electrolysis	24,000 kg/day	$7.12/kg ($50.21/GJ) *Current* $3.71/kg ($26.17/GJ) *Future*	Central production Tanker truck delivery (liquid H_2)	NAS/NRC, 2004

Note: Delivered hydrogen costs are on HHV basis unless otherwise specified.

[a] See report for additional storage and transport methods, including 100-mile pipeline, 1,000-mile pipeline, onsite consumption, and "gas station" delivery.

Appendix IV:

California Incentive Programs for Distributed Power Generation

The California Public Utilities Commission Self-Generation Incentive Program (SGIP) and the California Energy Commission (CEC) Emerging Renewables Buydown Program are the two primary programs that provide rebates for purchases of advanced power technologies in California. There are limits in eligibility to system sizes of 1.5 MW for the CPUC SGIP program (but the incentives only apply to the first 1 MW of system output) and 30 kW for the CEC renewables program. The CEC program is thus focused on smaller system sizes, including residential systems. While in recent years consistent with the CPUC program, the levels of incentives provided through the CEC program have recently been reduced somewhat (Table A-II below).

Table A-I: Distributed Power Generation Capital Cost Buy-Down Programs in California

Incentive Program and Level		Eligible Technologies
CPUC Self-Generation Incentive Program (extended through 2008 by AB 1685)		
Level 1:	$4.50/Watt up to 50% of project cost	PV, wind, renewable FCs, 30 kW to 1.5 MW
Level 2:	$2.50/Watt up to 40% of project cost	Non-renewable FCs w/ CHP, up to 1.5 MW
Level 3-R:	$1.50/Watt up 40% of project cost	Renewable microturbines, ICEs, and turbines, up to 1.5 MW
Level 3-N:	$1.00/Watt up 30% of project cost	Non-renewable microturbines, ICEs, and turbines, w/CHP and reliability criteria, up to 1.5 MW
CEC Emerging Renewables Program (new levels effective 1/1/04)		
$3.60/Watt		Renewable fuel cells and solar thermal electric less than 30 kW
$3.20/Watt		Solar PV less than 30 kW
$2.10/Watt for first 7.5 kW + $1.10/Watt thereafter		Wind less than 30 kW

For combustion-based technologies, the provision of these project support funds is contingent upon certain emissions criteria being met. These match the impending California ARB emissions regulation requirements for distributed generation of 0.014 lb/MWh NOx in 2005 and 0.07 lb/MWh NOx in 2007, with in 2007 the additional provision that combustion systems achieve at least 60% or better net efficiency (essentially requiring CHP for most technologies). Among other actions in his last days in office, former California Gov. Gray Davis signed legislation (AB 1685 - Leno) on October 12, 2003 that extended the SGIP program through 2008 and made the above emissions regulation provisions.

Appendix V:

California Governor Arnold Schwarzenegger

at the

University of California - Davis

Davis, CA

April 20, 2004

“Hydrogen Highways Network Announcement”

Thank you very much, Terry, for your wonderful introduction. I have to say that Terry is probably the best Secretary of the EPA that we've ever had in the history of our state. Give him a big hand. He's a great visionary.

I would also like to thank our other Secretaries that are here today. Resources Secretary Mike Chrisman -- a big hand for Mike Chrisman. And then we have Business, Transportation and Housing Secretary Sonny McPeak. A big hand for Sonny McPeak, a big hand for Sonny. And then we have here, and we already heard him, the Chancellor of UC Schwarzenegger -- I mean, Davis. You kept the name, huh? The Chancellor of UC Davis, Larry Vanderhoef. A big hand for Larry.

Anyway, this is really great, and I want to welcome all of you here. Thank you for coming. As you can see, this looks kind of like a movie set here, right? But of course it will be better, because what you see here today, this is the future of California and the future of our environmental protection.

All Californians deserve clean air and the promise of a healthy environment for generations to come, and this is exactly what we are doing here today. I will sign an executive order creating a public and private partnership that will create hydrogen highways all over the state of California by the year 2010. All across our highway system, hundreds of hydrogen fueling stations will be built, and these stations will be used by thousands of hydrogen-powered cars and trucks and buses.

This starts a new era for clean California transportation. These vehicles produce no emissions and no smog. They will clean the air and get rid of the smog that is hanging over our cities, and reduce the health problems caused by our pollution. Your government will lead by example and start using hydrogen-powered vehicles. And while we invest in a clean California, I will make sure that we get federal funds to support our innovative efforts.

As I have said many times, the choice is not between economic progress and environmental protection. Here in California growth and protecting our natural beauty go hand in hand. It goes together. A healthy environment leads to a healthy economy and a more productive workforce, and a better quality of life for everyone.

And as you know, we now have workers compensation reform. I signed the bill yesterday. That means it will be cheaper to do business in California. And of course this is great news for this effort, because now we are even more attractive for companies on the cutting edge of environmental technology. They will want to expand here, and they will want to do business here in our great state of California.

California will be the research capitol, the business capitol, and the job capitol of innovation and technology. We are the caretakers of our golden state, and the hydrogen highway will help us protect our extraordinary coastlines. It will help us protect our spectacular forests and our wonderful mountains and deserts, and make California a cleaner and healthier place for everyone. Thank you very much. Thank you.

And now, let's sign the bill. Let's create some action.

Appendix VI:

California State Treasurer Phil Angelides

to the

Commonwealth Club

San Francisco, CA

April 12, 2004

"Catching the Green Wave:

Believing Again in the Promise of California"

It is not only an honor to be invited to address the Commonwealth Club—it is a genuine pleasure. I mean that. Where else in California can you find a more tough-minded gathering of citizens and leaders engaged in thoughtful debate? Where else can you find Californians more willing to venture into the thickets and brambles of public policy and ask difficult questions? There is no audience more attuned to the wider sweep of events, to the long-term implications of the choices we make, than this one.

It is little wonder that testing one's mettle here at the Commonwealth Club has become mandatory duty for any self-respecting public servant aspiring to higher office.

No, that is not an announcement.

But you have my word: You will be among the first to know.

You asked me here today to discuss an initiative we recently launched in the State Treasurer's Office called the Green Wave. I am especially excited about this effort, because I think it shows what we can aspire to and achieve when we marry public investment to public purpose.

Put simply, the Green Wave calls on CalPERS and CalSTRS—the nation's largest and third-largest public pension funds, with combined assets of over $270 billion—to invest some of that capital in a way that simultaneously produces solid financial returns, creates jobs in California, cleans up the environment here and around the world, and builds the wealth and strength of our state.

I believe that this initiative can be a model for the nation. It will show that we can pursue green policies that build our economy while meeting our green-eyeshade duty to protect and grow the assets of our pensioners and taxpayers. If we begin to think creatively and look beyond the next fiscal quarter. If we once again ask the basic question: How can we use California's abundant wealth to build a better future?

For most of the second half of the 20th Century, California was defined by our unrivaled quality of life, a quality of life that we enjoyed because of the forward-looking investments and policies of the postwar generation of our state's leaders.

Our parents and grandparents invested to build the nation's greatest higher education system. They enacted California's groundbreaking commitments to coastal protection and environmental quality. They took risks to build the enterprises and develop the technologies that thrust California into the front rank of the global economy. To the world and the rest of the country, California was always the place where America's future was being born.

Sadly, that does not seem as true today. As I travel the state, I meet more and more Californians expressing doubts about our future and troubled about where they see our state heading.

It is not hard to understand their worries. Four years after the stock market topped out and the dotcom bubble burst, they see a state budget still bleeding red ink as politicians in Sacramento fail to face fiscal reality**.** They see a California drifting with the currents, its ambition furled and its course to the future uncertain.

Family breadwinners spend more and more time commuting to and from work on gridlocked freeways. Parents worry about the quality of their kids' schools and the rising cost of college. Whether the issue is the worsening air quality in the Central Valley or the inability of millions of California families to afford a home or health insurance, there is an increasing sense that our quality of life—the very idea of California—is at risk.

And at the very time when we should be thinking big to confront these challenges, when we should be building our competitive strength and laying the foundations for California's future success in the global economy, we are on the verge of reneging on historical commitments, in areas like higher education and transportation, that have been the underpinning of our prosperity.

I ask you: When did California stop believing—and investing—in its future?

Ladies and gentlemen, we have big work ahead of us.

Just consider one issue: how to protect our environment, our quality of life and our economic strength as California's population grows from today's 36 million to 46 million by 2025. That is the equivalent of adding the whole state of Michigan to California over the next two decades. We cannot sustain California's environmental quality and livability, and ultimately our economy, unless we embrace new ways of thinking and make investments that support smart growth, sustainable development and environmental preservation.

Look at the price we are already paying for our lack of foresight in transportation alone. In 2000, traffic congestion in California cost us an estimated $21.7 billion in lost time and fuel. Traffic congestion not only hurts our productivity—it is also a primary contributor to the state's poor air quality. According to the American Lung Association, eight of the nation's 24 worst air quality basins for ozone pollution are here in California.

By not thinking ahead, we risk degrading our environment and diminishing the very quality of life that is key to our economic competitiveness.

These are big challenges, and they are going to require that we think big. And invest big.

Let me say, the temptations are always great—in politics as well as business—to limit our vision to the next election, or to the next earnings report. To avoid investments that require patience and, yes, short-term sacrifice. But I believe that we must again begin taking the long view.

Think of what our world would look like today if we had actually heeded the lessons of the oil shocks of the 1970s, if we had followed through on policies promoting energy independence through conservation and the development of alternative fuels. We do not talk enough in this country about the linkage between our environmental policies and our foreign policy, but over the last five decades we have allowed our fate to be perilously tied to the politics and turmoil of the Middle East. Our dependence on fossil fuels has not only contributed to environmental damage. More than once, we have even seen our national security jeopardized and our entire economy thrown into recession as a consequence of our addiction to oil.

As laudable as it is for the president to talk, however briefly, about being the first nation to put a man on Mars, I believe that President Bush ought instead to be challenging us be the first industrialized nation to free ourselves from the grip of fossil fuels.

Not likely from a president and a party who believe that the jury is still out on global warming!

I still shudder when I think of the tragedy of the 2000 election—millions of environmentally minded voters rejecting the author of Earth in Balance and helping to elect the worst president our environment has ever seen, a president who turned our nation's energy policy over to a still undisclosed cabal of energy company executives and lobbyists, whose one true passion on the issue of the environment has been to drill in the Arctic National Wildlife Refuge.

Ladies and gentlemen, we need to start taking the long view again.

I still believe—and I know that the vast majority of Californians still believe—that we can do great things. In spite of all our problems, we have within our grasp the promise of greatness that has always propelled California forward.

It is in this spirit—with an eye toward California's economic and environmental future—that we launched the Green Wave initiative. The Green Wave seeks to harness the wealth of California's pension funds to encourage the development of alternative fuels and new environmental technologies, to address the challenges presented by pollution, growth and global warming, and ultimately to make money for our pension funds by catching the wave of innovation in environmental technology in the years to come.

Let me talk for a few minutes in specific terms about the four pieces of our initiative.

First, I have urged CalPERS and CalSTRS to build on our record of activism in support of corporate reform by adopting an environmental corporate governance program. We will call on corporations throughout America and the world to provide more robust, detailed reporting on their environmental practices and risks. And we will mobilize other major pension funds to join us in seeking sounder environmental management practices throughout corporate America.

Shareholders deserve to know whether the companies in which they are investing are going down the prudent path by adopting environmental practices that will allow them to thrive in a world of increasing environmental concern and regulation. Or whether they are taking the path of denial, risk, liability and cost.

We have learned, particularly in the corporate scandals of the last few years, that corruption can lurk in the shadows of secrecy, and that if you do not have transparency, shareholders—and the entire community—suffer.

Take a seemingly unconnected issue, like global warming—it is a problem that we do not tend to think about in terms of its direct economic impact. But that is not how the most sophisticated investors see it. Swiss Re, the world's largest life and health reinsurer, recently estimated that the annual economic cost of natural disasters, aggravated by climate changes, could double to over $150 billion in the next ten years, leading to $30 to $40 billion a year more in insurance claims. If, in the coming years, a company you are investing in is faces such risks, you will want to know. You have a right to know. And California's pension funds ought to demand to know.

The second element of the Green Wave initiative calls for a half-billion dollar investment in environmental technology. There is no question in my mind that the environmental technology sector is going to be one of the growth industries of the world—and if we are forward-thinking, it will be a major growth sector in the California economy.

Think of all the people around the developing world flocking to urban areas, of the consequent need for new technologies to deliver clean water and affordable energy that does not foul the air. Think of the expanding economies of the former Soviet bloc looking to repair the damage of a half-century of industrial development that was pursued without concern for the environment. Think, in our own country, of our need for energy and transportation technologies that will help us reach the goals of energy independence and sustainable development, that will help us deal with toxic contamination in our cities.

I want to say here and now that California should own this industry. Today, 45,000 people in the European Union are employed in wind-power manufacturing alone. And the global market for renewable energy is estimated to reach as much as $1.9 trillion by 2020. California was once a world leader in renewable energy. We need to lead the way once again.

California has the scientists, engineers and research institutions to be on the leading edge of environmental technology. It has the manufacturing expertise and skilled workers. It has the culture of entrepreneurship and the tradition of imagining the next new thing, sometimes at the lab bench, sometimes in a garage. It has the venture capital network to fund and nurture start-up companies. It has a citizenry eager to preserve California's environment. Ladies and gentlemen, California should own this industry.

Under the Green Wave initiative, CalPERS and CalSTRS will partner with the private sector to invest venture capital, expansion capital and project financing to spur along clean technology companies in California and across the country. This $500 million commitment—the first $200 million of which was approved last month—will directly create about 10,000 jobs and spawn hundreds of thousands more through the magic of the multiplier effect. And this investment has the potential to send a clear message across the nation: By investing in companies devoted to solving environmental problems, you can get returns, create jobs, bolster the economy and improve the environment.

The third element of our initiative takes a portion of the assets that we now invest in stocks and places a billion dollars with firms that actively manage environmentally screened portfolios. Americans now invest $29 billion in socially responsible funds. Many of those funds have proven over time that they can match or exceed the returns from traditional investment strategies because there is a strong correlation between long-term, responsible corporate practices and long-term value.

If we have learned one lesson from the corporate scandals of the last few years it would have to be that companies that cook their books to hype their returns over the short term leave stockholders holding the bag. The same is true of corporate environmental practices. Companies that hype their returns by degrading the environment will ultimately leave their stockholders — and all of us — with a big bill to pay.

The final element of the Green Wave initiative calls for a complete environmental audit of our pension funds' real estate holdings. CalPERS and CalSTRS have $16 billion invested in real estate. We own nearly 160 million square feet of office and industrial properties—to put that in perspective, there are about 35 million square feet of office space in all of downtown Los Angeles. We have an obligation to reduce our costs and increase the value of our portfolio by ensuring that our buildings are energy efficient and use best environmental practices. It is not just a matter of doing the right thing—it is a matter of doing the smart thing.

In advancing the Green Wave, I have kept firmly in mind that my first responsibility as State Treasurer and as a pension fund leader is to make sure that over the next 30 years our pension funds achieve the returns that will ensure that pensions get paid. Through the Green Wave initiative we can achieve this goal in two important ways.

The first is by keeping our eye out for the risks to our portfolio. Everything from corporate malfeasance to environmental liability to the risks from climate change.

The second is by discovering the opportunities in the exciting clean technology sector that can produce both good returns for the pension funds and good results for society.

Ladies and gentlemen, I still believe that here in California we can do great things. But to do so, we must once again make smart investments in our future.

There is no doubt that the environment is an area where the need for investment and strategic planning is acute, where the challenges are great, and where the threats to the quality of our life and economic competitiveness are real.

In this sense, the Green Wave is important. But it is just part of a larger discussion we need to have in California. A discussion about the immense challenges before us, about reviving public investment in a state that is living off the foresight of an earlier generation, about creating sustainable economic progress for decades to come.

That is a discussion I am looking forward to having with you and the rest of California.

And, with that, I would be happy to answer any questions.