California Hydrogen Blueprint Plan

Volume 2 May 2005

CALIFORNIA
HYDROGEN
HIGHWAY
NETWORK

California Environmental Protection Agency

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TIAX LLC (Cupertino and Irvine, California offices) and the Energy Independence Now Coalition prepared this document under the direction of the California Environmental Protection Agency and the California Air Resources Board (the lead sponsoring agencies).

The work described in this document and the attached reports was performed by members of the Executive Order Team, Systems Integration Team, Societal Benefits Team, Economy Team, Implementation Team, Rollout Strategy Team, and Public Education Team. The Advisory Panel provided advice to these various teams. Further information on these entities is described in this report.

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Statement

This Blueprint Plan was a collaborative effort by many people (see next page), most of whom contributed focused sections or passages involving specialized areas of expertise. The participation of, and contributions from individuals on the above teams and the Implementation Advisory Panel represents neither an endorsement of the final report and its findings or recommendations, nor a verification of a review of the final report, by the individuals or the organizations they represent.

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Table of Contents

Table of Figures

Table of Tables

Forward from the Executive Order Team

Background

In the January 6, 2004 State of the State address, Governor Schwarzenegger sent a clear message that California would begin a course toward a sustainable transportation energy future when he spoke the words:

> *"I am going to encourage the building of a hydrogen highway to take us to the environmental future...I intend to show the world that economic growth and the environment can coexist.*
>
> *And if you want to see it, then come to California."*

On April 20, 2004, the Governor signed Executive Order S-7-04 calling for the development of the California Hydrogen Blueprint Plan. On the same day he designated the University of California-Davis' hydrogen station as Station #1 of the California Hydrogen Highway Network (CA H2 Net).

A Public-Private Partnership

Since that time, more than 200 volunteer experts have engaged in the development of the California Hydrogen Blueprint Plan (Blueprint Plan). Volume I contains the Executive Order Team's recommendations to the Governor and Legislature. It summarizes what needs to be done, the estimated costs over the next five years, and an Action Plan containing recommended next steps. This volume, Volume II, reflects the assembled work of the Implementation Advisory Panel and the five Topic Teams. The findings and recommendations contained in this volume draw from the five individual Topic Team reports as well as the expert guidance of the Advisory Panel.

This Blueprint Plan was not intended to be a consensus document, and its contents reflect the diversity of the stakeholders involved in the process. The information and analysis contained in Volume II provides the technical underpinnings and expert assessments that give the Blueprint Plan its significance and value.

The Executive Order Team would like to acknowledge the hard work, dedication, patience, and care demonstrated by the Advisory Panel and the Topic Teams. While the magnitude of this effort was daunting and the timeline was ambitious, the result of this collaboration is a workable plan that balances a bold vision with a responsible path forward. Perhaps the most important result of the Blueprint Plan effort is the evolution of a strong and diverse community working towards a shared vision for California and beyond.

The contributors and the organizations they represent agreed to a shared set of core values that define the vision of a sustainable hydrogen economy for California. These core values are:

- Energy security and national security,
- A healthy environment and
- Economic growth and opportunity for California

What is the California Hydrogen Highway Network?

The California Hydrogen Highway Network (CA H2 Net) is a State initiative to promote the use of hydrogen as a means of diversifying the sources of transportation energy in order to ensure security, environmental and economic benefits. Implemented in phases, the Blueprint Plan outlines a path to 250 hydrogen stations and 20,000 hydrogen vehicles, which will help set the stage for full scale commercialization of a hydrogen economy. The broad mix of stakeholders involved in the CA H2 Net process has agreed that the CA H2 Net's 2010 goals are achievable.

The Blueprint Plan, based on the findings of the Topic Teams and the advice of the Advisory Panel, recommends the following critical path for the CA H2 Net:

- Implement the CA H2 Net program in phases, beginning as soon as possible with Phase 1. The transition to hydrogen fuel in California will require a long-term commitment and the best cooperative efforts of government, industry and consumers alike. The CA H2 Net is a long-term effort that should begin now.
- Biennial reviews should be undertaken, making periodic assessments of technological maturity, codes and standards, and commercial readiness for vehicles and other hydrogen-fueled products. Results of the biennial reviews should evaluate progress of implementation of the Blueprint Plan and inform the path forward to subsequent phases of implementation. Results of the biennial reviews should also help define timeframes for completion of Phases 2 and 3
- Phase 1: Target deployment of 50-100 hydrogen stations in California by 2010, including existing stations and those already planned through complimentary programs. Target deployment of 2,000 hydrogen-fueled light-duty vehicles, 10 heavy-duty vehicles, and 5 stationary or off-road hydrogen applications in California by 2010.
- Phase 2: Assuming successful completion of Phase 1 goals as judged by the results of biennial reviews, Phase 2 will expand the CA H2 Net to include 250 fueling stations. In tandem with the 250 stations, a deployment of 10,000 hydrogen-fueled light-duty vehicles, 100 heavy-duty vehicles, and 60 stationary or off-road hydrogen applications will be targeted.
- Phase 3: Target deployment of 20,000 hydrogen-fueled light-duty vehicles, 300 heavy-duty vehicles, and 400 stationary or off-road hydrogen applications. The number of stations may remain the same at 250, however volumes of hydrogen dispensed at these 250 hydrogen stations will be increased significantly due to the expanded fleet of hydrogen vehicles in the state.

Table A provides an overview of the three recommended phases, in terms of types and estimated numbers of hydrogen applications.

Table A. Estimated number of stations and light-duty vehicles by Phase.

Phase	Stations	Light-Duty Vehicles	Heavy Duty Vehicles	Stationary/Off-Road Applications
Phase 1 by 2010	50 – 100	2,000	10	5
Phase 2	250	10,000	100	60
Phase 3	250	20,000	300	400

Why Do We Need It?

Today, as it has been for more than a century, the vast majority of the world's vehicles are powered by fossil fuels. They have provided a relatively cheap and reliable means to power our vehicles. In the last few decades, however, there has been a growing realization that, for at least two reasons, we cannot continue to rely on fossil fuels. First, the supply of fossil fuels is increasingly insecure. The growing world demand for petroleum may soon exceed supply; and easily accessible petroleum supplies are dwindling[1]. Almost 60% of the petroleum imported into the United States[2] is from geopolitically unstable areas of the world. Second, the burning of fossil fuels produces pollution that damages human health and greenhouse gases that contribute to the unsustainable climate change of the planet.[3]

Hydrogen, as a solution to these problems, has the potential to revolutionize the ways we harness the world's energy resources. Hydrogen is a fuel and an energy carrier. As an emerging transportation fuel, hydrogen is driving innovative new designs of high-efficiency vehicles that offer important environmental and energy diversification benefits. It can be used in fuel cells that are more than twice as efficient as gasoline engines. These same fuel cell vehicles (FCVs) have no tailpipe or fueling emissions other than pure water vapor. Hydrogen can be used in high efficiency, stationary fuel cells to provide electricity, heating, and cooling for homes and businesses – all with very low environmental impacts. This Volume of the Blueprint Plan assesses the current status of hydrogen infrastructure and end use technologies. Due to the rapid progress being made in the pursuit of hydrogen technologies, this technological assessment should be updated on a regular basis.

While the societal benefits of hydrogen accrue over time, other near to mid-term solutions that provide a path to sustainability should be implemented in the interim. Near- to mid-term solutions that can help to minimize the negative impacts of fossil fuels include improved fuel economy through innovative new technologies such as hybrid electric vehicles, low rolling resistance tires and engine improvements such as more

[1] This is an increasingly recurring theme in the petroleum industry as evidenced most recently in: "ChevronTexaco Warns of Global Bidding War," by Deepa Babington, Reuters, February 15, 2005; "Shell cuts oil reserves again as profits soar," by Tom Bergin, Reuters, February 3, 2005; "Shell, Exxon Tap 'High Cost' Oil Sands, Gas as Reserves Dwindle," Bloomberg, February 18, 2005.

[2] "Crude Oil and Total Petroleum Imports Top 15 Countries", United States Department of Energy—Energy Information Administration, February 23, 2003.

[3] Intergovernmental Panel on Climate Change, 2001. Third Assessment Report of the Intergovernmental Panel on Climate Change

efficient transmissions and cylinder displacement on demand. However, the sooner California achieves a viable and sustainable alternative to fossil fuels the better off the State will be from an economic, national security and environmental perspective.

California is uniquely qualified to play a leadership role in accelerating hydrogen technologies and ensuring that the hydrogen economy moves forward in the smartest way possible. California is already positioned as a world leader in development and demonstration of hydrogen technologies. Well established programs are in operation at places such as: the California Fuel Cell Partnership, the South Coast Air Quality Management District, the Stationary Fuel Cell Collaborative, California's universities and research centers, over 100 private sector companies, and leading national laboratories. A commitment to and investment in the California Hydrogen Highway Network would help grow and sustain California's leadership position into the future.

What were the Key Findings?

Volume II of this Blueprint Plan summarizes the guidance of the Implementation Advisory Panel and the findings of the five Topic Teams. Each Topic Team's work was focused on one of five key issue areas relevant to the implementation of the Hydrogen Highway Network; 1) Rollout Strategy, 2) Societal Benefits, 3) Economics, 4) Implementation, and 5) Public Education. The findings of each Topic Team were submitted in the form of an independent report to the Executive Order Team.

The Rollout Strategy Team evaluated the various technologies that produce and use hydrogen in terms of availability and industry readiness, technical and economic barriers, and environmental considerations, for the three phases of implementation. The Team established siting criteria to deploy hydrogen stations throughout California and identified lessons learned from past alternative fuel vehicle programs.

The Societal Benefits Team quantified the societal impacts of the hydrogen production and end-use pathways broadly defined to include those most likely to be commercially and technologically viable in the 2010 timeframe and beyond. Environmental, social and health benefits of the transition to a hydrogen-based transportation system were examined, as well as methods to rank and prioritize implementation options with regard to these benefits. The Team also considered policies that could incentivize pathways with greater societal benefits.

The Economy Team estimated the cost of the various hydrogen station types now feasible for deployment, identified the number and mix of stations needed to provide fueling for various vehicle deployment scenarios, summarized the overall cost for those station scenarios, and identified a range of potential funding options for meeting those costs. For frame of reference and purposes of comparison, the Team also considered some of the external costs of the current petroleum-based transportation economy.

The Implementation Team examined the existing body of codes and standards and permitting processes for hydrogen fueling stations and developed recommendations for resolving gaps, insufficiencies or areas of overlap. In the absence of a history of safety statistics for the insurance industry to use to underwrite insurance policies for hydrogen stations, the Team also investigated options for insuring hydrogen stations during the early stages of infrastructure deployment.

The Public Education Team developed a detailed outline for translating the Governor's hydrogen vision and call to action into messages and communication action items directed to specific, key audiences. The Team identified key audience groups and the respective core messages they need to hear, as well as specific target audience challenges and opportunities. The Team also considered cost examples and examples of existing programs, background information on the key target audiences, and policy considerations.

Together, the findings from the five Topic Teams provide the foundation that supports the recommendations made in this Blueprint Plan. Because the status of hydrogen technology and commercialization changes almost daily, these findings should be reevaluated during subsequent biennial reviews of the Blueprint Plan to ensure the development of the CA H2 Net proceeds efficiently and responsibly.

Phase 1 Action Plan

Based on the guidance of the Advisory Panel and the supporting findings of the Topic Teams, this report contains a set of recommendations from the Executive Order Team in the form of an Action Plan that should enable the deployment of the CA H2 Net and the successful commercialization of hydrogen in California. The Action Plan for Phase 1 follows.

Form a public/private partnership in cooperation with stakeholders to site stations, build the CA H2 Net and procure vehicles

The Blueprint Plan was developed through a tremendous process of partnership and cooperation with stakeholders. The partnership and cooperation should continue through the implementation of the CA H2 Net.

- A cooperative partnership will ensure that the stations and the end uses (light duty vehicles, heavy duty vehicles and stationary/off-road applications) are deployed in tandem.
- The CA H2 Net should continue to employ the California station build-up philosophy. The initial stations should be located in major urban areas near the fleets that are expected to use the first vehicles. Stations should next be located along major interstates that connect the urban areas. These linking stations will facilitate travel between major urban areas.
- An independent review of CA H2 Net and the state of hydrogen technologies should be undertaken every two years.

The Governor's budget should propose the funds for Phase 1 of the CA H2 Net.

- Initial station deployments have typically been fifty percent cost-shared between industry and government. Funding to complete the first 100 stations should be provided by the State on a 50/50 match basis with the private sector.
- Vehicle incentives should be provided by the State during Phase 1
- The cost to the State for incentives of both hydrogen stations and vehicles is a $10.7 million dollar annual investment for 5 years.

- The California Environmental Protection Agency (Cal/EPA) should recommend the source of funding.

Set and adhere to environmental goals during implementation of the CA H2 Net.

- The CA H2 Net should achieve a 30 percent reduction in greenhouse gas emissions relative to comparable uses of today's fuels and technologies by 2010
- The CA H2 Net should utilize 20 percent new renewable resources in the production of hydrogen for use in vehicles by 2010, and increase annually thereafter.
- The CA H2 Net should not result in the increase of emissions of toxic or smog forming pollutants.

Legislation to support use of hydrogen for transportation should be enacted.

- The State should enact legislation and establish policies that help create a business and regulatory climate favorable for establishment of hydrogen infrastructure, including:
    - Establish hydrogen as a "transportation fuel"
    - Designate the State Fire Marshal's Office as the lead agency responsible for adopting hydrogen codes and standards, coordinating authorities having jurisdiction and their permitting processes, and training emergency first responders to address hydrogen incidents
    - Amend the appeals process for station siting so that the decision of the State Fire Marshal's Office on an appeal is binding and final

Initiate an outreach plan.

- An outreach plan to inform the public of the benefits and objectives of the CA H2 Net should be initiated and led by Cal/EPA.

The CA H2 Net Blueprint Plan has identified a number of significant benefits associated with implementing a hydrogen highway network. Hydrogen can greatly reduce our dependence on petroleum, provide numerous environmental and public health benefits, and create economic opportunities including new jobs in California.

The opportunity to lead the world by creating the beginning of a hydrogen economy is before us. By implementing the recommendations in this report, we will open the door to a sustainable transportation energy future. The phased approach and built-in review process recommended in this Blueprint Plan ensure a thoughtful, prudent path forward and responsible level of investment.

1.0 Introduction and Background

This section provides an overview of Executive Order S-7-04, which was signed by Governor Schwarzenegger in early 2004 to initiate the CA H2 Net. It describes the process used to develop the Blueprint Plan required in the Executive Order. This section also provides a basic description of hydrogen, how it is used today, and its potential to become a major fuel and energy source in California.

The California Hydrogen Highway Network (CA H2 Net) has been initiated to help expedite commercialization of hydrogen as a transportation fuel and energy source in California.

1.1 Executive Order S-7-04

Governor Arnold Schwarzenegger signed Executive Order (EO) S-7-04 in April 2004, which formally launched an important new hydrogen initiative as part of California's larger energy and environmental plan. This executive order calls for:

- Designation of California's 21 interstate freeways as the "California Hydrogen Highway Network;"
- Planning and building a network of hydrogen fueling stations along these roadways and in the urban centers they connect so that by 2010, every Californian needing hydrogen fuel will have access to it;
- Accelerating progress in hydrogen use through public incentives and financing mechanisms, such as general obligation bonds, or revenue bonds with repayment mechanisms; joint power agreements; and partnerships with public and private entities; and
- Promoting economic development opportunities resulting from increased utilization of hydrogen for stationary and mobile applications.

Key milestones and objectives for the CA H2 Net to achieve in the 2010 timeframe are identified in the Executive Order, including the following:

- Develop a sustainable plan to deploy growing numbers of hydrogen fueling stations in tandem with commercial availability and rollout of hydrogen-fueled vehicles and other products.
- Make a State commitment to collaborate with auto makers and fuel cell manufacturers to ensure that hydrogen-powered cars, buses, trucks, and generators become available for purchase by State, regional and local agencies.
- Include an increasing number of clean, hydrogen-powered vehicles in California's state vehicle fleet, when possible to be purchased during the normal course of fleet replacement.
- Establish safety standards, building codes and emergency response procedures for hydrogen fueling installations and operation of hydrogen-powered

vehicles, with training procedures in place for permit agencies, building inspectors and emergency responders.

- Develop the CA H2 Net in such a way that the total production of hydrogen used for transportation is from a significant and increasing percentage of renewables.
- Provide incentives to encourage the purchase of hydrogen-powered vehicles, generators, and other devices.
- Establish an outreach and education plan for these various coordinated efforts.

1.2 Development of the Blueprint Plan

Cal/EPA led a collaborative process to develop a Blueprint Plan to implement the CA H2 Net as directed by EO S-7-04. To manage this effort, Cal/EPA established an Executive Order Team (EO Team), chaired by the Cal/EPA Secretary. The EO Team respectfully accepted the counsel of an Advisory Panel consisting of high-level representatives from industry, California state agencies, federal and local government agencies, academia, and public advocacy groups[4]. The Advisory Panel worked closely with the EO Team and the Topic Teams to provide the basis for the recommendations and Action Plan to implement the CA H2 Net.[5]

Volunteer experts provided invaluable and detailed technical, financial and policy inputs that helped shape the Blueprint Plan. These volunteers represented a wide array of government agencies, private industry, academia, and environmental organizations. More than 200 individuals served on five separate "Topic Teams": Rollout Strategy, Societal Benefits, Economy, Implementation, and Public Education[6]. Each of the Topic Teams submitted an independent report to the EO Team. All are publicly available.[7]

Most of the technical input contained in this report originated from work of the five Topic Teams. Over the course of about six months, each Topic Team performed detailed analyses, solicited input at public meetings, and presented key findings to the EO Team and Advisory Panel. Through this process, each Topic Team was provided with input and guidance from the Advisory Panel to finalize its findings.

The outcome of this entire process is a two-volume report called the California Hydrogen Blueprint Plan (Blueprint Plan). Volume I contains the EO Team's recommendations to begin implementation of the CA H2 Net. Volume I summarizes an Action Plan, the estimated costs to the State over the next five years, and recommended next steps. Volume II contains key findings of the Topic Teams and the corresponding counsel of the Advisory Panel in support of the recommendations in Volume I.

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[4] The individual members of the Advisory Panel are acknowledged on pages iv-v.

[5] The participation of individual Advisory Panel members does not represent an endorsement of the Blueprint Plan or any of its conclusions and recommendations, by the individuals or the organizations they represent.

[6] The Topic Team members are individually listed at the beginning of Volume II of the California Hydrogen Blueprint Plan.

[7] Reports are available at www.hydrogenhighway.ca.gov

The Blueprint Plan will be updated every two years in accordance with Executive Order S-7-04. The updates will be critical to ensure that the CA H2 Net promotes an accelerated and intelligent transition to a hydrogen economy.

1.3 Basic Description of Hydrogen and its Uses

Hydrogen is the simplest and lightest element. Although hydrogen is all around us and accounts for 75 percent of the entire universe's mass,[8] on Earth it is found only in combination with other elements. For example, hydrogen readily bonds with oxygen to make water, and with carbon to make organic matter. Before it can be used as a fuel, hydrogen must be separated from these other elements. The process to "produce" hydrogen requires energy, just as it takes energy to make fossil-based transportation fuels like gasoline and compressed natural gas (CNG). For example, hydrogen fuel can be produced from molecules called hydrocarbons by applying heat. This "reforming" process is currently used to make hydrogen from natural gas, and is the cheapest method of hydrogen production. An electrical current can also be used to separate water into its components of oxygen and hydrogen, in a process called electrolysis. In addition certain types of algae and bacteria use sunlight as their energy source and give off hydrogen under certain conditions.[9] Once separated using these various processes, hydrogen exists as a gas under normal conditions, although it can be supercooled (-423 ^{o}F) into its liquid form. In either case, hydrogen fuel consists of two hydrogen atoms bound together (H_2).

Today, hydrogen is primarily used for industrial processes such as ammonia manufacturing and petroleum refining. It has also been widely used in NASA's space program as fuel for the space shuttles, and in fuel cells that provide heat, electricity and drinking water for astronauts. A fuel cell is an elegant and simple device that produces a direct and continuous current of electricity using an electrochemical reaction between hydrogen and oxygen. All of the world's major automobile manufacturers are developing hydrogen fuel cell vehicles because of the incredible potential fuel cells hold as a commercially viable, clean and efficient power source. Stationary applications of fuel cell systems can be used to generate environmentally friendly electricity and usable heat. In both of applications of fuel cells, California is likely to be the earliest U.S. market for commercialization.

Fuel cell vehicles are in fact electric vehicles (EVs). Like battery-powered EVs, fuel cell vehicles use efficient and fast response electric-drive systems. Fuel cells can be thought of as batteries that never lose their charge -- hydrogen can be continuously supplied from an external fuel tank, and oxygen can be extracted from air. However, instead of electrons being stored within the chemicals in the battery, they are supplied in the form of a hydrogen molecule. Electrons are released in the fuel cell by way of a reaction between hydrogen and a catalyst (typically platinum). The simplicity of fuel cells impart many desirable attributes to fuel cell vehicles including zero emissions, fuel economy that is twice as high as most internal combustion engines that we drive today, a driving range required by consumers and refueling times comparable to gasoline vehicles.

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[8] California Energy Commission, *Energy Story: Chapter 20*; online at http://www.energyquest.ca.gov/story/chapter20.html.

[9] Ibid.

Figure illustrates the basic operation of a vehicle powered by a hydrogen-fueled proton exchange membrane (PEM) fuel cell, which is the type being developed for automotive applications. A more technical description of how PEM fuel cells convert hydrogen to electricity is provided in Section 3. While today's prototype fuel cell automobiles appear similar to conventional vehicles on the outside, the drive train components and their layout, as well as other systems, can be quite different.

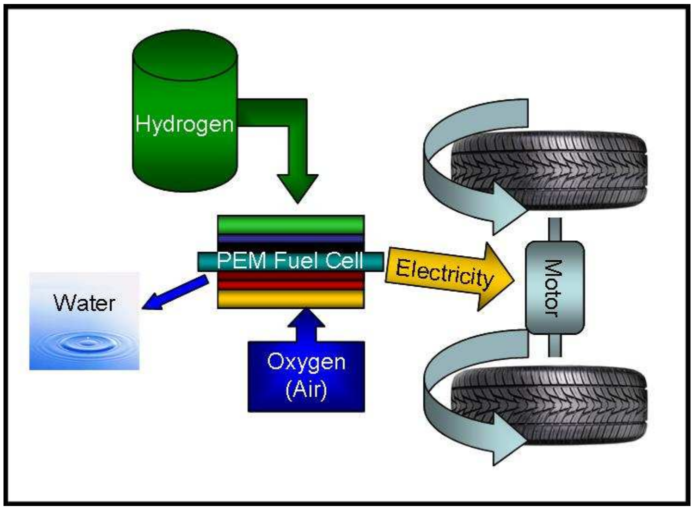

Figure 1.1 – Basic Operation of a Hydrogen Fuel Cell Automobile.

Hydrogen can also be used to power vehicles with internal combustion engines (ICEs), much as natural gas is currently used. At least two major automobile companies are working to develop and commercialize hydrogen ICE vehicles. Hydrogen ICE vehicles have near-zero tailpipe emissions and offer other benefits, as further described in this report. Presently the cost of a hydrogen ICE vehicle is less than 25% of a hydrogen fuel cell vehicle. Compared to gasoline ICEs, hydrogen ICEs offer better mileage, do not consume fossil fuels and have extremely low emissions.[10]

Section 3 of this report, as well as some of the individual Topic Team reports, contain extensive details about these types of hydrogen vehicles and the benefits and challenges associated with their commercialization. Other end-use applications for hydrogen, such as stationary fuel cells, are also described.

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[10] Equivalent to the Air Resources Board's Low Emission Vehicle rating of SULEV

2.0 Why Hydrogen?

Hydrogen has the potential to address California's long-term energy and environmental challenges. Over the next few decades, hydrogen fuel and technologies will help reduce petroleum dependency in our transportation sector, improve reliability in our electricity generation system, and provide important environmental benefits. Development of hydrogen technologies can also help create new jobs and businesses in California. The level of benefits that can be achieved in a given timeframe will ultimately depend on the penetration of hydrogen vehicles and energy technologies into the market. Although the impacts of this activity to create a hydrogen economy are expected to be small in the early years, the CA H2 Net actions will be a catalyst for commercialization and will lead to significant long term benefits that will increase with time.

Commercialization of vehicles and technologies that use hydrogen as fuel can provide compelling benefits to California. Potential benefits include a more diverse and secure transportation energy supply, an improved environment, and the opportunity for economic growth. Each of these benefits is described further below.

2.1 Energy Diversity and Security Benefits of Hydrogen

2.1.1 California's Long-Term Energy Strategy

California's transportation sector is nearly 100% dependent on gasoline and conventional diesel, both of which are non-renewable and in finite supply. Demand for these fuels in California alone has grown nearly 50 percent in just the last 20 years and will continue to grow. At the beginning of this decade, California had a population of 33.8 million people, driving 24 million registered vehicles, and consuming more than 17 billion gallons per year of gasoline and diesel fuel. By 2020, it is projected that 45.5 million Californians will operate 31.5 million vehicles consuming about 24 billion gallons of gasoline and diesel fuel.[11]

Already over 34% of California's crude oil comes from foreign sources[12], and that number is expected to grow. Meanwhile, California's petroleum refining capacity has not kept pace with this demand. In fact, since the mid-1990s, in-state refining capacity has decreased nearly 20 percent, and California has shifted from being a net exporter of petroleum to a net importer. During this period, a combination of refinery outages, marine and distribution constraints and other factors has led to volatile gasoline and diesel prices. [13]

Figure illustrates the impact of near term measures to reduce California's dependence on petroleum. The petroleum reduction goal cannot continue to be met with near term remedies after 2035 without additional actions. The increase in petroleum demand after 2035 is due to California's growing population and increased vehicle usage.

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[11] California Energy Commission, California Air Resources Board; *Reducing California's Petroleum Dependence, Joint Agency Report*; August 2003; Publication Number P600-03-005f.

[12] California Energy Commission, *Foreign Sources of Crude Oil Imports to California 2003*, January 19, 2005. http://www.energy.ca.gov/oil/statistics/2003_foreign_crude_sources.html

[13] Ibid.

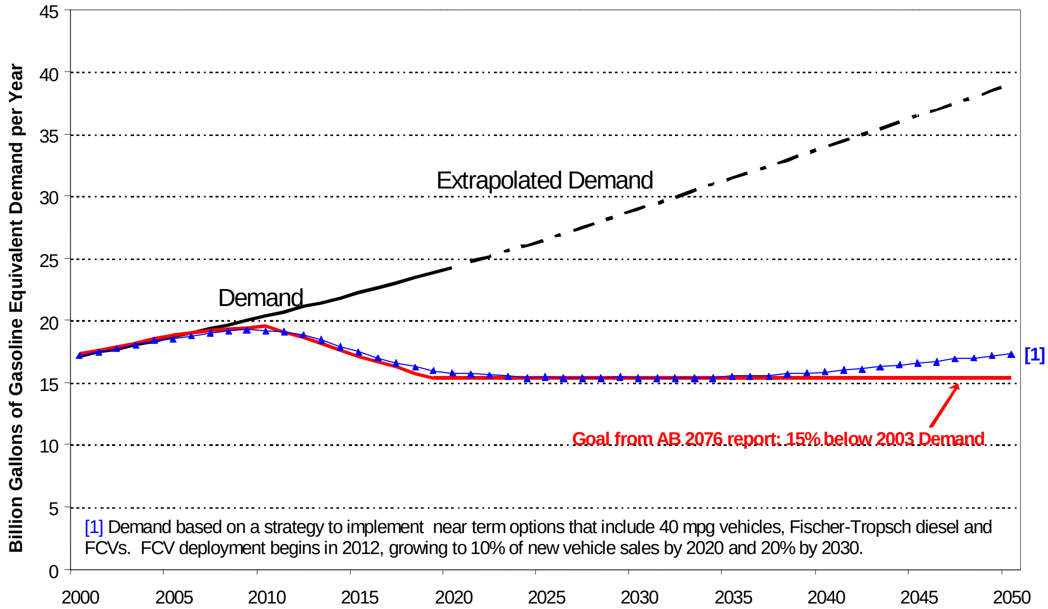

Figure 2-1 – Projected Growth in Demand for On-road Petroleum Fuels[14]

Several options are available to reduce the demand for petroleum transportation fuels. One effective means is conservation through production and use of more fuel-efficient motor vehicles, such as gasoline hybrid-electric vehicles. Greater use of available non-petroleum fuels, such as natural gas and synthetic diesel fuel, can also reduce petroleum demand. Over the next two decades, these and other near-term approaches can collectively reduce demand for petroleum fuels to current levels or below. Beyond then, greater use of non-petroleum fuels will be necessary to meet the ever growing demand for clean transportation fuel. A detailed assessment by the California Energy Commission and the Air Resources Board showed that from an environmental and economic standpoint, hydrogen fuel cell vehicles provide an attractive long-term approach for continuing to reduce California's petroleum dependence.[15]

2.1.2 Diversification and Stabilization of California's Energy Supply

Hydrogen offers compelling benefits that cut across energy needs for transportation, electricity generation, and climate control needed for our buildings. Energy stations are electricity production units that can provide hydrogen for vehicle fueling in addition to heating, cooling and power for buildings. Various types of fuel cells are emerging as viable electricity-generation technologies for energy stations. Energy stations are a single unit that includes a stationary power source, such as a fuel cell, and a hydrogen fueling station. Like electricity, hydrogen is an *energy carrier*, meaning that it can be used to store, move and deliver energy in a usable form to consumers. One advantage hydrogen offers as an energy carrier over electricity is that it is easier to store. Hydrogen can be used to store renewable energy that is intermittent in nature, for time periods when the

[14] Ibid.

[15] Ibid.

demand exceeds the electricity supplied by the renewable resource. These very useful attributes of hydrogen can help improve and stabilize the ability of our existing electricity system to meet growing consumer demand.

In summary, hydrogen's unique characteristics as a fuel and energy carrier can displace fossil fuel use in our transportation sector while also helping our over-extended electricity production and transmission system. Together, these attributes offer strong potential for hydrogen to diversify and stabilize California's overall energy portfolio.

2.1.3 Hydrogen Production From Renewable Resources

An infrastructure based on hydrogen and renewable resources is inherently sustainable in nature. The term "renewable resources" (or simply "renewables") refers to resources such as wind, solar, geothermal, and waste resources such as biomass. All of these types of renewable resources are available in California and can be used to produce hydrogen. Hydrogen produced from renewable resources has no emissions of any pollutants, and reduces reliance on limited resources such as oil and natural gas. Further, to the extent California takes the lead in developing technology to produce hydrogen from renewable resources, our state is in an attractive long-term economic position as demand for such technology is expected to grow significantly worldwide.

Some stakeholders argue that renewable resources would be better utilized, from the perspective of public health and environmental protection, to produce electricity rather than hydrogen. The amount of energy required to meet the goal of 20% hydrogen production from renewables is very small. Even if the renewable resources dedicated to producing hydrogen were shifted to the electricity sector, the impact would be less than 0.1 percent of the total sector. Additional discussion about this issue is provided in Section 4 and the Societal Benefits Topic Team report.

2.2 Environmental Benefits

Reducing emissions from on- and off-road mobile sources is a top priority in California because motor vehicles are the dominant source of air pollution and toxics health risk in California.[16] California's 24 million gasoline- and diesel-fueled vehicles directly and indirectly cause a variety of serious pollution problems in our state. Although tremendous progress has been made to reduce vehicle emissions, on-road mobile sources (e.g., cars, trucks, and buses) still account for about 47 percent of California's ozone ("smog") precursor emissions (reactive organic gases and oxides of nitrogen). Off-road vehicles contribute 23% of the state's smog precursor emissions. In addition, motor vehicles and their fuels are the largest source of toxic air emissions in California. Particulate matter from diesel-fueled engines (diesel PM) contributes more than 70% of the known risk from air toxics today. The top three contributors to potential cancer risk for Californians (diesel PM, 1,3 butadiene, and benzene) come primarily from motor vehicles.[17]

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[16] California Air Resources Board, "Proposed 2003 State and Federal Strategy for the California State Implementation Plan," accessed online at http://www.arb.ca.gov/planning/sip/stfed03/revsect2.pdf, March 2005.

[17] California Air Resources Board, "Reducing Toxic Air Pollutants in California's Communities," accessed online at http://www.arb.ca.gov/toxics/brochure.pdf,. March 2005.

California's transportation sector is also the single largest contributor of greenhouse gases in the State. Greenhouse gases emitted by motor vehicles include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and hydrofluorocarbons (HFCs).[18]

It is not just the actual vehicle operation that creates these air pollution problems. Adverse environmental impacts occur during virtually every step associated with using motor vehicles. Making a fair comparison of the full air quality impacts of various motor vehicle types requires characterization of as many of these "source-to-wheel" emissions as possible. The steps in the entire process that create emissions for a gasoline or diesel vehicle are illustrated in Figure below.

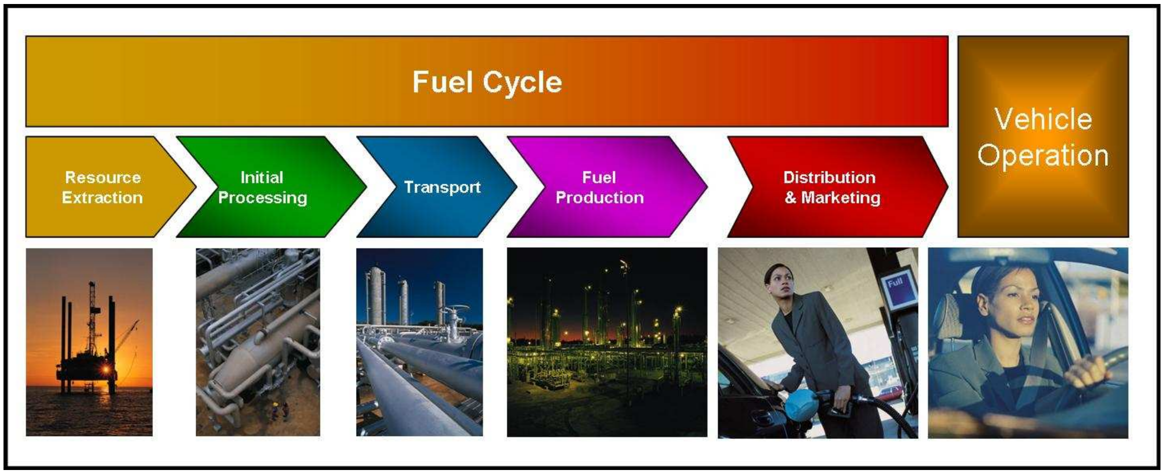

Figure 2-2 – Source-to-Wheel Steps Resulting in Emissions[19]

Based on this type of analysis, the major air quality benefits of using hydrogen to power motor vehicles or generate electricity fall into two major categories, as described below.

2.2.1 Smog-forming and Toxic Emissions

The refining of petroleum into gasoline and diesel fuel results in emissions of reactive organic compounds, including toxic compounds, oxides of nitrogen and particulate matter. Refineries are typically one of the largest stationary sources of emissions in the state. The distribution of gasoline from the refinery to the retail service station and into the vehicle fuel tank results in fuel evaporation emissions at every point of transfer. Combusting petroleum fuels in vehicles results in emissions of reactive organic gases (some of which are toxic), oxides of nitrogen, carbon monoxide, and particulate matter.

Emissions associated with the production of hydrogen vary according to the source of the hydrogen. If hydrogen is produced using electrolysis and the electricity is derived from renewable resources then the source-to-wheel emissions are zero—the entire fuel cycle is sustainable. Evaporative emissions during the distribution phase are not significant since even if the hydrogen leaks out, it does not create environmental problems. If hydrogen is

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[18] California Air Resources Board, "Report to the Legislature and the Governor on Regulations to Control Greenhouse Gas Emissions from Motor Vehicles, accessed online at http://www.arb.ca.gov/planning/sip/stfed03/revsect2.pdf, March 2005.

[19] These images illustrate the fuel cycle for petroleum fuel production, distribution and usage.

used in a fuel cell the only emission is water.[20] In a hydrogen combustion engine, only near-zero amounts of oxides of nitrogen are emitted. For the entire source-to-wheel cycle, hydrogen vehicle emissions of reactive organic gasses, oxides of nitrogen and carbon monoxide are clearly less than gasoline or diesel, while the relative comparison for particulate matter depends on how the hydrogen is made.

This discussion points to the importance of producing hydrogen in the most environmentally sound manner. Options are available that are zero emitting for the entire fuel cycle, such as the use of solar energy to power electrolysis.

2.2.2 Greenhouse Gas Emissions

Emissions of carbon dioxide (CO_2) from the world's rapidly growing population of motor vehicles are a major source of "greenhouse gas" (GHG) emissions. According to the California Air Resources Board, "an ever-increasing body of scientific evidence" attributes global climate change to GHG emissions.[21] Over time, global climate change can impact our ecosystems, economy, and health. Global warming from GHG emissions can affect mountain snow packs, critical for water storage in much of the state, as well as increase the frequency and severity of storms. Furthermore, a warming climate could exacerbate urban smog, which is already at unhealthful levels in many of California's cities. Strategies to commercialize and deploy vehicles that operate on low-carbon and zero-carbon fuels, such as natural gas and hydrogen, can simultaneously help reduce emissions of GHGs and improve local air quality.

As with smog-forming emissions, the source-to-wheel greenhouse gas (GHG) emissions of hydrogen vehicles depend on the method of hydrogen production. In this case emissions also depend on what type of vehicle uses the hydrogen, because fuel cell vehicles require less hydrogen than ICE vehicles that burn hydrogen. And both hydrogen fuel cell and ICE vehicles are more efficient than comparable gasoline vehicles. Notable is that production of hydrogen from renewable-based electricity results in near zero emissions. Reforming of natural gas also results in lower fuel cycle greenhouse gas emissions than gasoline. However, production of hydrogen using grid electrolysis results in greater GHG emissions than gasoline. Again this points out the importance of developing the CA H2 Net using the lowest-emitting technologies for producing hydrogen.

2.3 Economic Development Benefits

California has a long history of being at the forefront of emerging high-technology industries. State officials have recognized that these industries can create jobs as technologies develop and flourish in the world marketplace. It is estimated that more than 100 companies are working on prototype hydrogen-related technologies in

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[20] Hydrogen fuel cell vehicles will remain zero-emitting throughout their useful lives. This solves one of the most difficult problems with controlling pollution from "mobile" sources – how to eliminate in-use emissions due to deterioration of emissions control systems. Phasing in progressively larger numbers of hydrogen fuel cell vehicles will provide California with an important advantage in controlling air pollution from its ever-growing vehicle population.

[21] California Air Resources Board, FAQ: Reducing Climate Change Emissions from Motor Vehicles, accessed online at http://www.arb.ca.gov/cc/factsheets/ccfaq.pdf, 12/22/04.

California; examples include hydrogen production systems, fuel cells, hydrogen storage systems, and safety-related devices. Many companies have initiated similar efforts in other states. If California continues to lead in creating demand for hydrogen fueling stations and products, companies with related technologies are more likely to choose our state to locate new technology centers and manufacturing facilities. Expansion of hydrogen-related research, development and demonstration efforts will help generate new jobs, businesses, and industries in California.

3.0 Overview of Hydrogen Technologies

The complete process to produce hydrogen and consume it in end-use applications involves many "enabling" technologies. This section, which is based on the extensive work done by various Topic Teams, summarizes the status of hydrogen technologies that will be integral building blocks of the CA H2 Net and California's path toward achieving a hydrogen economy. It describes some of the key barriers to commercializing emerging hydrogen technologies, as well as existing or needed efforts to overcome them. Although a snapshot, this information helps to convey the strong promise that hydrogen offers as a clean and abundant fuel for California, as well as the associated challenges.

3.1 The Baseline: Today's Petroleum Infrastructure and Vehicles

California has approximately 24 million vehicles on the road today that operate on gasoline and diesel fuels. Today's vehicles and infrastructure have been developed over many decades to a very high level of technological maturity and commercial success. To serve the fueling needs of these vehicles, gasoline and diesel are widely available at approximately 10,000 retail stations. Processes and equipment to make petroleum fuels, and infrastructure to distribute and dispense them, have also evolved over many decades. Gasoline and diesel are both energy-packed liquid fuels. This attribute helps make on-board fuel storage relatively simple and inexpensive, and has met consumer's demand for driving range. Though highly volatile, prices at the pump have been tolerated by consumers, based on the billions of gallons that Californians purchase each year. [22]

There have been at least 100 hydrogen-fueled vehicles placed on the roads in California. Nearly 40 hydrogen fueling stations exist or are planned for deployment within the next 5 years. Today's hydrogen vehicles are still essentially prototypes, although automobile manufacturers are making significant advancements. Much additional work must be done before deploying hydrogen vehicles on a wide scale to make sure they will meet government requirements and consumer expectations. Hydrogen production and distribution technologies for vehicle fueling are also being developed—continued development and demonstration of viable technologies are needed for industry to determine the most cost-effective solutions. Largely due to these technological challenges and simple low-volume economics, the costs of hydrogen vehicles and fueling station technologies, as well as the hydrogen fuel itself, are relatively high today.

Actions are being taken to bridge the gap between the current dominance of gasoline and the introduction of hydrogen as a transportation fuel. Demonstrations are underway for pre-commercial hydrogen vehicles and fueling stations. These programs are essential for manufacturers to ensure that their prototype vehicles and products meet rigorous demands for performance, safety, durability, reliability, and other key requirements. With additional work, hydrogen production technologies can achieve higher system efficiencies and lower environmental impacts. For hydrogen stations, public accessibility and consumer friendliness should be improved. It is essential for fuel suppliers and

[22] Part of the reason that these fuels are inexpensive is that their prices do not reflect market "externalities." An externality is a cost (such as damaged human health resulting from air pollution caused by combustion of petroleum fuels) or benefit (such as increased fuel supply diversification) of a market transaction that is not paid for nor borne by those making the transaction.

energy companies to develop the technologies and systems that can provide hydrogen safely and at competitive prices.

The following sections summarize the technological and commercialization status of hydrogen technologies that will be integral building blocks of the CA H2 Net and California's path toward achieving a hydrogen economy. They are described in the following order and general categories:

1. Infrastructure: Technologies that produce, distribute, or dispense hydrogen
2. End-Use Applications: Vehicles and devices that consume hydrogen

3.2 Hydrogen Production, Distribution and Dispensing Technologies

Gasoline and diesel fuels are produced from crude oil (the feedstock) in refineries that are generally located regionally and distribute via pipeline and tanker trucks. This basic model is one option for producing and distributing hydrogen. However, other options exist that may be more conducive to the characteristics of hydrogen, including the fact that it can be produced from a wide variety of relatively simple, renewable feedstocks. In several cases, it is most economical to produce hydrogen at the point of use.

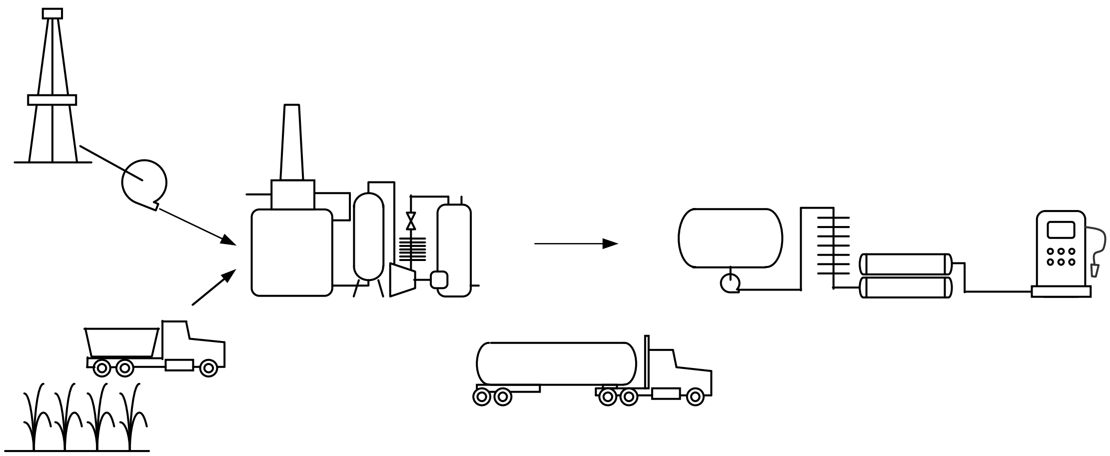
3.2.1 Overview of Hydrogen Infrastructure Components and Options

The hydrogen fuel cycle refers to the sequential steps involved in producing hydrogen and dispensing it into the fuel tanks of vehicles (or other end-use devices). There are a number steps, and there are many technology options for each step. For most scenarios, the hydrogen fueling infrastructure steps or stages include the following processes:

- The "feedstock" source must be obtained or extracted, and then transported to the hydrogen production facility (if not already on site).
- The hydrogen must be produced (separated) from the feedstock.
- The hydrogen must be transported from the production unit to the fueling station (this step is eliminated for on-site or distributed production scenarios).
- The hydrogen must go through final preparation (this step could occur at the production site or at the fueling station, depending on its intended use and whether it is compressed or liquefied).
- The final hydrogen fuel must be stored at the fueling station (a "mobile" refueler strategy might circumvent this step, as well as other steps).
- The hydrogen fuel must be dispensed into vehicles (or other hydrogen applications), with compatible types of on-board hydrogen storage technology and safe, effective station-vehicle interface.

This subsection and the ones that follow provide more detail about the technologies and processes most likely to play a role in the launch years of commercialization for hydrogen-fueled products and fueling stations. Extensive discussion and analysis of various hydrogen infrastructure technologies is provided in the Rollout Strategy Topic Team report, under work performed by the Production and Delivery Subgroup.

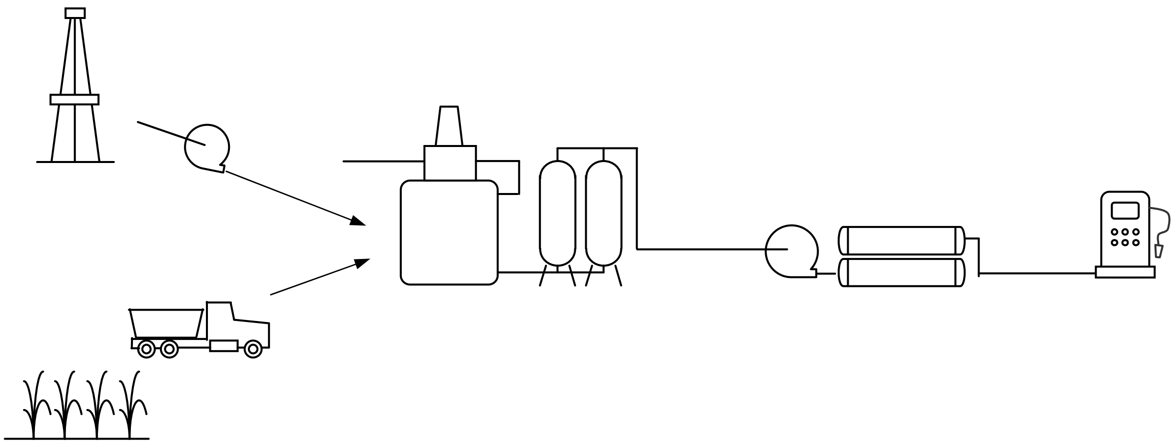
It is useful to categorize hydrogen production methods according to whether the process is *centralized* or *distributed*. The diagram and table in Figure depicts the infrastructure steps and options associated with centralized (offsite) hydrogen production. The diagrams and tables in Figures 3-2 A and 3-2 B depict the infrastructure steps and options associated with two types of distributed (at the site) hydrogen production: on-site reforming (Figures 3-2 A and 3-2 B A) and on-site electrolysis (Figures 3-2 A and 3-2 B B).



Feedstock	Production	Delivery	Station Components	Dispensing
Non-renewable (e.g., natural gas, liquid hydrocarbons) or renewable (e.g., biomass, ethanol)	Reforming (e.g., for natural gas) or gasification (e.g., for biomass), plus liquefaction or compression (for delivery), and possible carbon sequestration	By liquid tank truck (shown), compressed hydrogen tube trailer, or pipeline where available	Includes delivered hydrogen storage, pumping or compression, high-pressure cascade (for compressed hydrogen dispensing), and other components	For vehicles with compressed, liquid, hydride, or other hydrogen storage systems

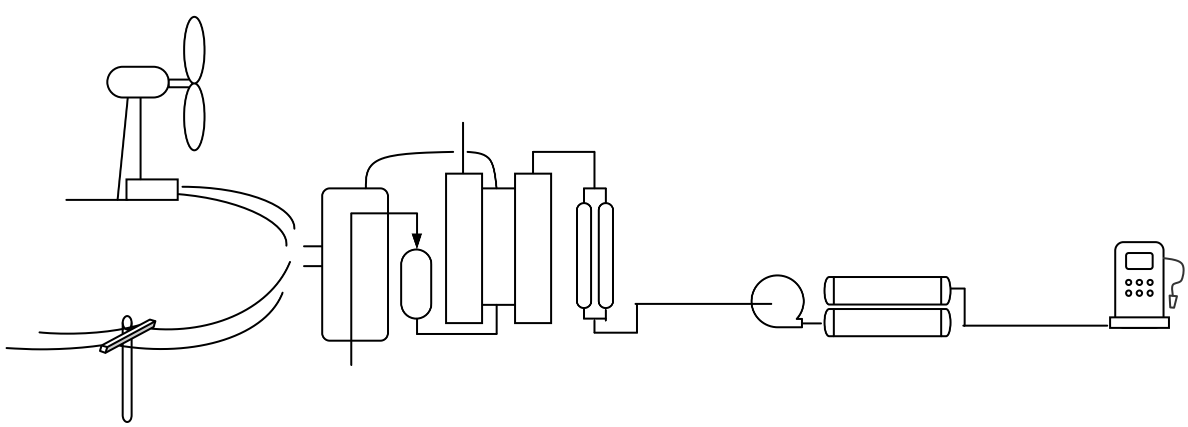
Figure 3-1 – Hydrogen fuel cycle steps and options with centralized (off-site) production

Figures 3-2 A and 3-2 B **A. With On-site Reforming**



Feedstock Production and Transportation	Reformer	Station Components	Dispenser
Non-renewable (e.g., pipeline-delivered natural gas) or renewable (e.g., truck-delivered ethanol, methanol, biomass)	Typically a steam, partial oxidation, or autothermal reformer including purification, etc. May include gasifier for feedstocks such as biomass.	Includes hydrogen compression, high-pressure storage cascade, controls, and other components	Typically for vehicles with compressed or hydride hydrogen storage systems

Figures 3-2 A and 3-2 B **B. With On-site Electrolysis**



Electrical Generation and Transmission	On-site Electrolysis	Station Components	Dispenser
Renewable, non-renewable, or combination	Typically PEM or alkaline electrolyzer units including purification, etc.	Includes hydrogen compression, high-pressure storage cascade, controls, and other components	Typical for vehicles with compressed or hydride hydrogen storage systems

Figures 3-2 A and 3-2 B – Hydrogen fuel cycle steps and options with two types of distributed (on-site) production

In addition to above-noted scenarios, hydrogen (typically from centralized production) can also be dispensed into vehicles by mobile fueling units, such as the one shown in Figure . This mobile fueler is basically a trailer with a pressure vessel cascade, dispenser, controls, and safety equipment. The use of mobile fuelers in conjunction with California's current excess merchant hydrogen[23] capacity can provide a low initial-cost option for temporarily fueling hydrogen vehicles, avoiding the risk of potentially stranded higher-cost assets.

Graphic courtesy Air Products and Chemicals

Figure 3-3 – Mobile fuelers refilled at central plants provide a low initial-cost infrastructure option

The steps outlined above collectively make up the hydrogen fuel cycle. It is the process used to produce the hydrogen that most profoundly affects the potential benefits and costs of this fuel. Key hydrogen production technologies and methods are discussed in the next subsections.

3.2.2 Hydrogen Production by Reforming Various Feedstocks

Reformers produce hydrogen from hydrocarbon (e.g., methane) or alcohol feedstocks by stripping away the hydrogen. Most reformers also include a water-gas shift process, in which the reformate (carbon monoxide (CO) + H_2) reacts with water to *shift* oxygen and thereby produce carbon dioxide (CO_2) and more hydrogen. The most common reformer technologies are steam methane reforming (SMR), auto-thermal reforming (ATR), and partial oxidation (POX). The hydrogen is usually purified in a pressure swing adsorption (PSA) or membrane unit.

Hydrogen has been produced from natural gas in large SMR plants for decades. Some of these plants provide hydrogen that is dedicated to processes such as petroleum refineries, and some plants produce "merchant" hydrogen that is liquefied or compressed and delivered by truck to industrial customers. There are two large-capacity merchant hydrogen SMR and liquefaction plants in California (Sacramento and Ontario). Hydrogen is routinely delivered from these "central" plants to hydrogen fueling stations. A local pipeline connects one hydrogen SMR plant south of Los Angeles with nearby refineries, and plans are in place to install a hydrogen fueling station that will be supplied by this pipeline.

[23] "Merchant" hydrogen refers to hydrogen that has been produced for delivery to industrial customers.

Application of reformers for distributed (on-site) hydrogen production at the fueling station (refer back to Figures 3-2 A and 3-2 B A) requires a substantial down-sizing of the reformer and purification technologies that are used for central hydrogen production. A few hydrogen fueling stations have on-site SMRs (e.g., the Las Vegas station shown in Figure), and a number of companies are commercializing small-capacity reformers and integrated systems (reformer-compressor-storage-dispenser) specifically for hydrogen vehicle fueling. The co-location of hydrogen fueling at CNG stations also offers potential capital benefits if the same equipment can be utilized for both hydrogen and CNG and the hydrogen purity standards can be met. Although not yet commercially demonstrated, providing for this capability offers substantial capital savings potential and merits evaluation as the technology progresses.

Figure 3-4 – The combined hydrogen fueling and energy station in Las Vegas, Nevada, features an on-site natural gas reformer. Commissioned in June 2002.

Reformers can also process alcohol feedstock and therefore can operate with renewably produced ethanol or methanol. These feedstocks may be promising for providing hydrogen to rural or remote locations. Alternatively, if ethanol stations are built throughout the state to serve the current flexible fuel vehicles, it may be cost effective to reform ethanol at these stations to hydrogen.

Gasification technology can produce hydrogen from feedstock such as biomass, coal, or petroleum coke. These solid feedstocks are *gasified* by reacting them with steam and air or oxygen at high temperatures to produce "syngas," which typically contains CO, CO_2, hydrogen, methane (CH_4), and water vapor. The syngas is further processed in a shift reactor to increase the hydrogen content. The non-hydrogen components are removed in a purifier.

Gasifiers enable hydrogen to be produced from renewable feedstocks such as agricultural wastes (biomass). This is a potential strategy for producing hydrogen without consuming fossil fuels. It can also result in low, zero, or even negative net GHG emissions, particularly if it includes carbon capture and sequestration.

3.2.3 Hydrogen Production by Electrolysis

Electrolysis systems use electricity to split water into its component elements –hydrogen and oxygen. This technology has been used for decades in industrial, military, and space applications. Sometimes the hydrogen is utilized and sometimes the oxygen is utilized (e.g., for life support). Electrolyzers have also been used to produce on-site hydrogen at fueling stations (refer back to the scenario depicted in Figures 3-2 A and 3-2 B B). This infrastructure strategy provides the opportunity to produce hydrogen from non-fossil sources with zero emissions of GHGs and criteria pollutants.

An important parameter affecting the economics of hydrogen produced by electrolysis is the electrolyzer efficiency, which is defined as the ratio of the hydrogen output heating value to the input electrical energy. An electrolyzer achieving 100 percent efficiency would require about 33 kW-hr (of electrical energy) per kg of hydrogen production. Real electrolyzer efficiencies can range from approximately 60 to 90 percent, depending on the technology, size, and manufacturer. Total efficiencies for hydrogen fueling stations with electrolyzers are somewhat lower, due to balance of plant processes such as compressing and storing the hydrogen.

Electrolysis units that produce hydrogen are fully commercialized and can be purchased from several companies. This presents a near-term option for producing hydrogen for California's hydrogen vehicles. One issue that has attracted attention involves the potential to use renewable energy sources such as solar or wind to power these types of electrolyzers. There are subtle options and tradeoffs associated with this strategy, and the choices made will affect the environmental and energy benefits that can be realized. For example, hydrogen produced by electrolysis using electricity from the grid could increase GHG emissions relative to the fuel cycle for a conventional vehicle if the grid is predominantly powered by fossil fuels. Conversely, hydrogen generated by electrolysis that is powered by renewable resources results in the elimination of any GHG emissions. Additional discussion about this important issue is summarized in this report in Section 4. Many of the details for these options and tradeoffs are discussed in the Topic Team reports and their cited references.

Figure 3-5 – The Honda energy station in Torrance, California. The hydrogen is produced by an electrolyzer powered by solar panels.

Error! Reference source not found. shows the Honda renewable energy station in Torrance, California. The electrolyzer (and also the compressor and other components) is visible under the sail. The solar panels are to the right of the station.

3.2.4 Stationary Fuel Cells on the CA H2 Net

Fuel cells are devices that convert the chemical energy of a reaction directly into electrical energy. A variety of fuel cell types are being developed for a wide array of applications. The two fuel cell applications that are most relevant to this report are: 1) transportation applications that use fuel cells to power motor vehicles, and 2) "stationary" applications that use fuel cells to generate electricity and usable thermal energy.. Four basic fuel cell types are being developed for one (or both) of these two applications: 1) proton exchange membrane, 2) phosphoric acid, 3) molten carbonate, and 4) solid oxide. These technologies are distinguished by their distinct components, their operation temperature, the type of fuel and oxidant, whether the fuel is processed outside (external reforming) or inside (internal reforming) the fuel cell, and other parameters.

A detailed tutorial about fuel cell technologies is beyond the scope of this report, but numerous websites provide excellent sources for further reading.[24] Fuel cells are relevant because they "are an important enabling technology for the hydrogen economy and have the potential to revolutionize the way we power our nation, offering cleaner, more-efficient alternatives to the combustion of fossil fuels."[25] It is within this context that fuel cells are further discussed below, starting with stationary fuel cell applications. This section discusses stationary fuel cells used in energy stations that *produce* a slipstream of hydrogen for vehicle fueling, and fuel cells that *consume* a portion of the hydrogen produced in the energy station.

3.2.4.1 Distributed Generation Energy Stations

As previously noted, the term "energy station" generally refers to a distributed generation (DG) system that co-generates electric power, thermal energy for heating and cooling and hydrogen for vehicle fueling. DG denotes the fact that the station produces power independent of, or in parallel with, the electric grid. DG is gaining importance in electricity grid planning as a means to enhance service reliability by adding new generation capacity at (or near) the point of use. DG has the added benefit of deferring or eliminating the need for new transmission or distribution lines. Co-generation is a highly efficient, potentially low-cost DG option that produces electricity and thermal energy. Fuel cell systems are emerging today as viable technology for co-generation in a variety of stationary (non-transportation) applications.[26] Larger-scale (megawatt) and smaller-scale (kilowatt) stationary fuel cell systems are being commercialized that can increasingly contribute to California's electricity-generation portfolio.

An energy station that contains a high-temperature fuel cell (HTFC) can *produce* a slipstream of hydrogen, in addition to its primary job of providing baseload electrical

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[24] For example, see the following websites: 1) www.stationaryfuelcells.org, 2) www.CaliforniaHydrogen.org, 3) www.fuelcellpartnership.org, 4) www.nfcrc.uci.edu, 4)www.fuelcells.org and 5) www.eere.energy.gov/hydrogenandfuelcells.

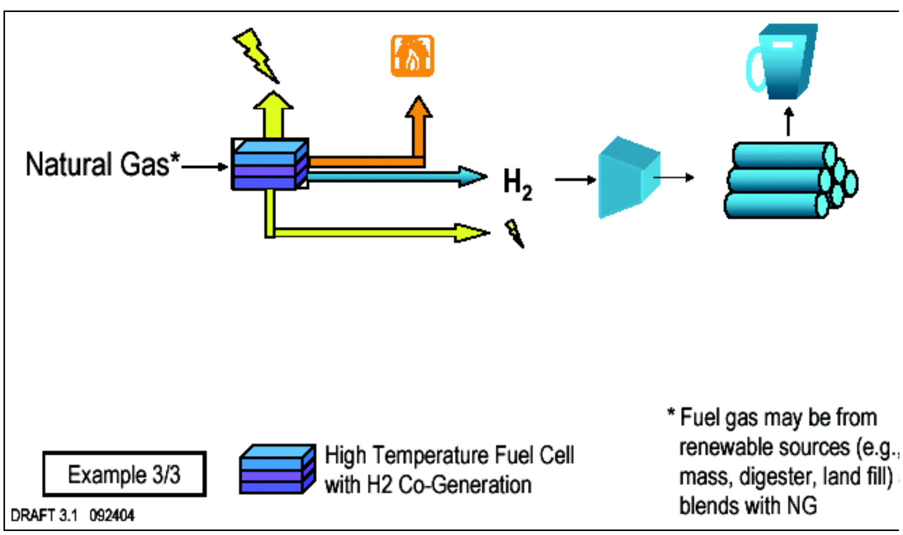
[25] U.S. Department of Energy, "Fuel Cells," accessed online at http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/, March 2, 2005.

[26] California Energy Commission, input to Blueprint Plan from Commissioner James Boyd and his staff, submitted by email, 12/20/04.

power and usable heat. The overall attractiveness of this energy station concept is the relatively high system efficiencies that can be achieved, including the process to produce hydrogen. The key enabling technology that results in the high overall system efficiency is a HTFC fueled with natural gas.

Two types of fuel cells are considered to be HTFCs. Solid oxide and molten carbonate fuel cells operate at or above 1200°F. These HTFCs can be configured to reform natural gas or renewable fuels such as digester gas directly into hydrogen to power the fuel cell.[27] As with all fuel cells, HTFC systems do not use all the fuel that is supplied. The unconsumed fuel is traditionally oxidized at the exit of the stack and used in other parts of the system before being exhausted as high-quality waste heat. With modifications to the current HTFC, the unused fuel can be used for cost-effective co-generation of hydrogen in a slipstream to the vehicle.

In the concept shown in Figure 3-6, a HTFC is fueled by natural gas that directly produces a slipstream of hydrogen for the vehicle fueling station. There are other candidate energy station configurations that are currently expected to be viable for co-generating hydrogen for vehicles. Like the one described above, these configurations receive natural gas (from fossil or renewable sources) and provide DG electric power, thermal energy, and hydrogen for a fueling station. Rather than producing hydrogen directly within an HTFC, these concepts use an electrolyzer or reformer (powered by the fuel cell or another device) to generate the hydrogen.



How it Works: Natural gas fuels a high-temperature fuel cell (HFTC), which produces electricity (yellow) and thermal energy (orange) for DG, while co-producing hydrogen on demand (blue) directly in the HTFC stack for vehicle refueling

Diagram courtesy of California Stationary Fuel Cell Collaborative

Figure 3-6 – An energy station that uses a high-temperature fuel cell system to generate hydrogen for refueling vehicles, electricity, and thermal energy.

[27] Like PEMFCs, solid oxide and molten carbonate fuel cells use the reaction of hydrogen and oxygen to make electricity. However, in these HTFCs, ions other than hydrogen cross the electrolyte (cathode to anode) to complete the reaction.

According to the California Stationary Fuel Cell Collaborative, "[the HTFC energy station] is viewed as potentially the most efficient, cost-effective, and environmentally sensitive means (to generate) hydrogen from natural gas." This method of hydrogen production is cost effective in part because the energy station can operate as a stand-alone, revenue-producing DG business if the demand for hydrogen fueling is low.[28]

In the concept shown in Figure 3-6, a HTFC is fueled by natural gas that directly produces a slipstream of hydrogen for the vehicle fueling station. There are other candidate energy station configurations that are currently expected to be viable for co-generating hydrogen for vehicles. Like the one described above, these configurations receive natural gas (from fossil or renewable sources) and provide DG electric power, thermal energy, and hydrogen for a fueling station. Rather than producing hydrogen directly within an HTFC, these concepts use an electrolyzer or reformer (powered by the fuel cell or another device) to generate the hydrogen.

Low temperature fuel cells (such as the PEM technology being developed to power motor vehicles) that must use pure hydrogen fuel can be used in energy station systems. The excess hydrogen[29] at a fuel station with a co-located PEM fuel cell can produce a direct current of electricity. Without the stationary fuel cell as an added hydrogen-consumption device, the station would waste hydrogen (through venting or flaring), or shut down and restart regularly to match hydrogen refueling demands. In either case, this would lead to increased waste and lower efficiency.[30] As an energy station, the added stationary fuel cell improves the hydrogen station's viability and economics, while also providing environmentally benign DG in the form of co-generation. If a renewable energy source such as wind is used to make the station's hydrogen, additional energy diversification benefits can be realized. Even though wind resources are not constant, hydrogen produced during peak wind activity can be used to store energy for generation of electricity when it is most needed.

Energy systems are available today, although deployments to date have been limited to demonstration scale. In addition to the systems described herein, other potentially beneficial configurations are being developed that involve stationary fuel cells consuming hydrogen. For example, energy stations with stationary fuel cells can be designed to provide efficient refrigeration for cooling, in addition to DG electricity and heat. These are often called combined cooling, heat, and power (CCHP) facilities. "Hybrid" hydrogen systems, which combine two different forms of power generation (e.g., a fuel cell and a gas turbine generator), can provide enhanced energy efficiency for some applications.

3.3 Hydrogen End-Use Applications and Technologies

Today, the transportation sector appears to be the main technology driver for commercializing hydrogen as a common fuel. All major automobile manufacturers and

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[28] California Stationary Fuel Cell Collaborative, "Position in Support of the Hydrogen Highway Initiative," submitted by Executive Director Ron Friesen in a letter to Dr. Shannon Baxter-Clemmons of Cal EPA, August 11, 2004.

[29] For example, a surplus of hydrogen might be available in the early years of station deployment, before large numbers of hydrogen vehicles are deployed. Or, this could occur during off-peak hours when vehicles aren't being refueled (storage exceeds use).

[30] The California Stationary Fuel Cell Collaborative, *Position in Support of the California Hydrogen Highway Network*, website (http://www.stationaryfuelcells.org), online September 2004.

several after-market conversion companies are developing vehicles that use hydrogen fuel cell and/or hydrogen internal combustion engines (H2ICE). This section therefore primarily focuses on the status of hydrogen vehicle technologies. However, there are other important end-use applications for hydrogen on the horizon. Hydrogen or hydrogen-natural gas blends could be used in stationary ICE generators for DG applications. Other "niche" products and applications may also emerge for hydrogen fuel. Examples include portable power products, premium backup power for telecommunications, and off-road equipment such as forklifts. Extensive discussion (including many niche applications) is provided in the Rollout Strategy Topic Team report.

3.3.1 Hydrogen Vehicles

Hydrogen can be used in vehicles with fuel cells or internal combustion engines as their primary energy-conversion devices. For both types of vehicles, the predominant overall power-producing reaction is between the hydrogen fuel and the oxygen in the air:

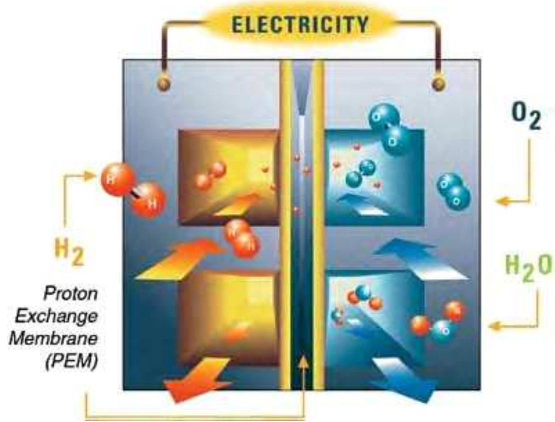
$$2\,H_2 + O_2 \rightarrow 2H_2O$$

Hydrogen fuel cell vehicles are considered zero emission vehicles (ZEVs) because they produce no criteria pollutants and cannot deteriorate over time to produce harmful emissions. H2ICE vehicles do produce oxides of nitrogen (NOx), although properly designed vehicles with state-of-the-art engines and after-treatment can achieve extremely low levels. Neither type of vehicle emits the greenhouse gas carbon dioxide (CO_2), which is produced by combustion of hydrocarbon fuels such as gasoline and diesel. See Section 4 for greater detail about the environmental implications of hydrogen-fueled vehicles relative to conventional vehicles. The status of hydrogen fuel cell and ICE vehicle technologies is summarized below. On-road vehicle applications are primarily focused upon, but the technologies and issues discussed also apply to off-road applications such as forklifts, locomotives, ships, and cargo-moving vehicles at ports.

3.3.1.1 Fuel Cell Vehicles

In fuel cell vehicles, the electric drive train is powered with electricity produced by an electrochemical reaction of hydrogen in the fuel cell. Figure illustrates the basic operation of a proton exchange membrane (PEM) fuel cell, which is the type used in automotive applications. PEM fuel cells can be combined in a side-by-side configuration called "stacks." Stacks are scalable to the needed power requirement. More fuel cells in a stack produce more power. Most of the moving parts and complexities of these fuel cell systems are associated with the "balance of plant" components, which are needed to perform functions such as air compression, water and thermal management, and power conditioning.

Proton exchange membrane (PEM) fuel cells are the type most commonly used for automotive applications.



Graphic courtesy California Fuel Cell Partnership

When hydrogen enters a PEM fuel cell, its electrons and protons are separated. A membrane in the cell selectively allows the protons to pass through, while the electrons are routed to provide the electricity to power the motor that propels the vehicle. On the other side of the membrane, the hydrogen combines with oxygen from the air to form water and heat.

Figure 3-7 – Basic operation of a proton exchange membrane fuel cell

The automotive industry has recognized the potential benefits of hydrogen fuel cell vehicles. According to the California Fuel Cell Partnership – which includes the membership of eight major automobile manufacturers – hydrogen fuel cell vehicles can provide the air quality benefits of battery-powered electric vehicles, combined with the driving range and convenience of conventional gasoline vehicles.[31] Benefits and advantages of fully commercialized hydrogen fuel cell vehicles are expected to include the following:

- Elimination of criteria pollutants and GHG emissions from the tailpipe
- Increased fuel efficiency
- Lower maintenance costs (fewer moving parts in the powertrain)
- Similar driving range to conventional vehicles
- Rapid acceleration and a quieter, smoother ride
- Compatibility with today's full complement of on-board electronics (entertainment features, Internet connections, GPS, etc.)
- Flexible car design
- Potential for lower manufacturing costs

Independently, and through organizations such as the California Fuel Cell Partnership, nearly every major automobile manufacturer is engaged in hydrogen fuel cell vehicle research and development, and most manufacturers have fielded on-road demonstrations with selected fleets. While today's prototype fuel cell automobiles look similar to conventional vehicles on the outside, the drive train components and their layout can be

[31] California Fuel Cell Partnership, website (http://www.fuelcellpartnership.org/fuel-vehl.html), online November 12, 2004.

quite different. Figure 3-8 shows photographs of prototype fuel cell vehicles, most of which have been built on existing, conventional vehicle platforms.

Figure 3-8 – Examples of Hydrogen Fuel Cell Automobiles

Efforts are also underway to develop advanced automotive designs that take full advantage of the configuration flexibility enabled by fuel cell power systems. For example, GM's concept "Hy-wire" vehicle shown in Figure 3-9 integrates the powertrain, fuel storage, and controls into a "skateboard" platform allowing considerable design flexibility for the remainder of the vehicle. Drive-by-wire controls (i.e., no mechanical linkage) help free up interior vehicle space.

Figure 3-9 – General Motor's advanced Hy-wire fuel cell vehicle (photo courtesy of GM)

Fuel cell power systems are also being developed for heavy-duty applications such as buses, trucks, locomotives and various types of off-road equipment. Transit buses look like the most practical and likely point-of-market entry for heavy-duty hydrogen vehicles. The Air Resources Board's Transit Bus Fleet Rule requires large transit agencies to deploy zero-emission buses, of which fuel cell buses are the primary choice. The California Energy Commission notes that hydrogen buses could be integrated into service with greater ease than light-duty vehicles, based on extensive past experience with vehicle demonstrations. One hydrogen bus uses as much fuel as 25 to 30 light-duty vehicles; this makes it easier for bus fleets to justify investments in hydrogen fueling stations than light-duty vehicle fleets. An added benefit is that buses have high visibility with the public, which can help educate people about the use and benefits of hydrogen fuel.[32]

Several California transit agencies are initiating plans for revenue-service demonstrations of hydrogen fuel cell buses, and are now installing the necessary hydrogen fueling infrastructure. Figure 3-10 shows two fuel cell buses tested by SunLine Transit in Thousand Palms, California. Fuel cell bus demonstrations are also being conducted in Europe[33], Asia[34] and Australia[35].

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[32] California Energy Commission, input to Blueprint Plan from Commissioner James Boyd and his staff, submitted by email, 12/20/04.

[33] http://www.fuel-cell-bus-club.com

[34] http://www.chinafcb.org/index-english.html

[35] http://www.dpi.wa.gov.au/fuelcells

Figure 3-10 – SunLine and other California transit agencies are testing fuel cell buses

Research is underway to improve the performance of PEM fuel cells used in vehicle applications. With private and government support, this work is being carried out by fuel cell companies (including members of the CaFCP), universities, and national laboratories. In particular, extensive efforts are underway to lower the costs of fuel cells and increase their durability. Much progress has been made, although continued improvements will be necessary to achieve cost and performance objectives established by the U.S. Department of Energy.

3.3.1.2 Internal Combustion Engine (H2ICE) Vehicles

Hydrogen can also be combusted in ICEs, much like gasoline or natural gas. Companies such as Ford, BMW, Hydrogen Car Co. and Collier Technologies are developing H2ICE vehicles in parallel with, or as nearer-term and more economic alternatives to, hydrogen fuel cell vehicles. H2ICE vehicle development work has been progressing in the U.S., Germany, Japan, and elsewhere since the 1970s and can be purchased today in California. These vehicles currently use conventional drivetrains and spark-ignition gasoline engines that have been modified to combust hydrogen. The conversion process is similar to (with some exceptions) converting an engine to run on natural gas. Key issues include power performance levels and backfire mitigation. Straightforward gasoline-to-hydrogen conversion results in a substantial power loss because the low-density hydrogen gas displaces much of the air induced into the cylinder during the intake stroke. However, the power density of H2ICEs can be improved by adding a supercharger or turbocharger. Owing to hydrogen's broad flammability limits and low ignition energy, ignition of the fuel-air mixture in the intake manifold (i.e., backfiring) was a problem in the past. Application of modern port-injection and computer control technologies have largely mitigated this problem.

H2ICE vehicles can achieve equivalent or better efficiency than comparable gasoline ICE vehicles.[36] Their fuel efficiency can be further improved through use of hybrid-electric drivetrains, similar to the way gasoline hybrids such as the Toyota Prius, Honda Civic and Ford Escape have achieved higher fuel economy. However, due to the inherent efficiency limitations of combustion engines, H2ICE vehicles are not expected to be as efficient as fuel cell vehicles. Unlike fuel cell vehicles, H2ICE vehicles do not require ultra-pure hydrogen fuel and are more tolerant of trace contaminants (e.g., sulfur compounds, which can hinder performance and efficiency of fuel cell systems), potentially lowering the cost of hydrogen fuel.

A few major automobile manufacturers have demonstrated hydrogen ICE vehicles that appear to be near commercial production readiness. Three examples of hydrogen ICE vehicles are shown in Figure 3-11. It is possible that some of these concepts will be sold with "dual-fuel" capability, meaning they can be operated either on hydrogen or a conventional fuel like gasoline (from separate fuel systems). This approach offers greater comfort for early consumers regarding fuel availability, which can be important until hydrogen stations become more plentiful. However, dual-fuel vehicles are unlikely to be optimized for either fuel, and this may compromise air quality benefits.

Figure 3-11 – Examples of hydrogen internal combustion engine (H2ICE) vehicles

Unlike fuel cell vehicles, H2ICE vehicles can operate on blends of hydrogen and compressed natural gas (which is sometimes referred to as HCNG). HCNG use, particularly in heavy-duty vehicles such as buses, is often viewed as a cost-effective strategy for utilizing a hydrogen fuel-supply infrastructure as it is being installed to support subsequent ramp-up of hydrogen fuel cell and/or H2ICE vehicle deployment. HCNG vehicles have also been shown to produce even lower NOx emissions and higher efficiency than their CNG counterparts.

[36] This comparison refers only to vehicle efficiency and does not consider fuel production, etc. At least one major manufacturer indicates that the efficiency of hydrogen ICE vehicles can exceed that of gasoline ICE vehicles.

3.3.1.3 Hybrids

Companies such as Quantum Technologies are developing aftermarket H2ICE vehicles that use hybrid-electric drive trains. For example, under South Coast Air Quality Management District sponsorship, a number of Toyota Prius gasoline hybrids (HEVs) are being converted to run on hydrogen for demonstration within various city fleets in Southern California. Manufacturers can use this technology choice to provide increased fuel efficiency, extended driving range, and cleaner emissions. Based on the success of gasoline hybrids, this approach to commercialization for H2ICE vehicles seems likely to be utilized.

Another "cross-cutting" technology involving hybridization is the plug-in hybrid electric vehicle (PHEV), which increases battery capacity (compared to normal HEVs) to support short range all-electric driving. PHEVs can use either ICEs or fuel cells as their auxiliary powerplants, but they are recharged similar to electric vehicles. Utilizing advances in battery capacity, PHEV technology can allow the use of smaller fuel cells or H2ICEs and also reduce hydrogen storage requirements. The result can be lower manufacturing costs, which may accelerate the deployment of hydrogen-fueled vehicles. Several universities and companies are currently developing prototype fuel cell PHEVs.

3.3.2 On-Board Hydrogen Storage Technologies

A significant technology challenge for commercialization of hydrogen vehicles (fuel cell or ICE) is to develop on-board hydrogen storage technology that can enable a hydrogen vehicle to obtain the same range as today's gasoline and diesel fueled vehicles.[37] Currently, to provide similar driving range as gasoline vehicles, on-board containment devices for hydrogen must be larger and heavier than gasoline or diesel fuel tanks. As described below, a variety of hydrogen storage technologies are under development, but all tend to be more complicated, more expensive, and larger or heavier than desirable at this time. The size, weight, and cost challenge for hydrogen storage tanks is partially offset by the fact that hydrogen vehicles are more efficient (as described above) than today's gasoline and diesel vehicles, and therefore do not need to store as much energy.

3.3.2.1 Compressed Hydrogen Fuel Tanks

The most common method for storing hydrogen fuel on vehicles is to increase its density by compressing hydrogen gas and storing it at a high pressure. On-vehicle hydrogen storage at 5,000-psi is most commonly used, but 10,000-psi storage has been certified for use and continues to advance through development and testing. Compressed hydrogen at 5,000 and 10,000 psi has about 10% and 15%, respectively, of gasoline's energy density (i.e., heating value per unit volume). Compressed hydrogen pressure vessels are extensions of technology that is well developed and fully commercialized for compressed natural gas (CNG) vehicles.

The tank construction is basically high-strength carbon fibers wrapped in layers over a thin aluminum or polymer tank liner. These tanks tend to be cylinder shaped, but other tank shapes are also being developed that conform to available vehicle spaces. Figure 3-

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[37] The U.S. DOE has identified on-board storage as the top technical barrier to hydrogen's future in the transportation market.

12 shows an example of an advanced-technology design for a 10,000-psi on-board hydrogen storage system.

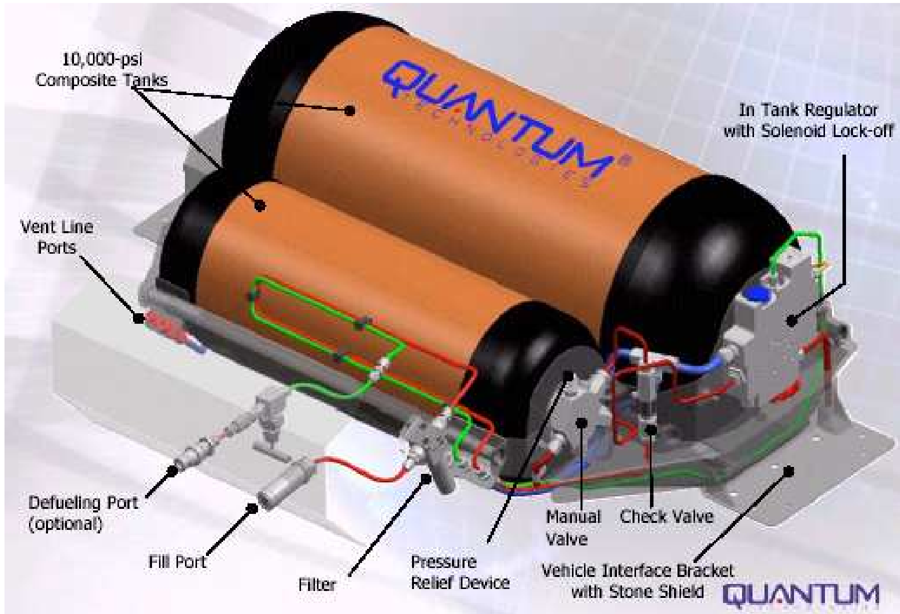

Photo courtesy Quantum Corp.

Figure 3-12 – Example of an on-board compressed hydrogen (10,000 psi) storage system.

3.3.2.2 Liquefied Hydrogen Fuel Tanks

Hydrogen is stored as a liquid in several commercial applications today (e.g., the U.S. space program), and this storage mode is being pursued for hydrogen vehicles by some automobile manufacturers. Hydrogen is a gas at ambient conditions. It must be cooled to approximately -420°F to condense into a liquid, and this refrigeration process requires considerable energy. However, liquid hydrogen has higher energy density than compressed hydrogen (about 25% of gasoline's energy density), so liquid hydrogen tanks are smaller and lighter than compressed hydrogen tanks containing the same quantity of hydrogen. At these cryogenic temperatures, the liquid hydrogen must be stored in vacuum-insulated fuel tanks that minimize heat leaks and the resulting hydrogen venting. An example of an on-board storage system for liquefied hydrogen is shown in Figure 3-13.

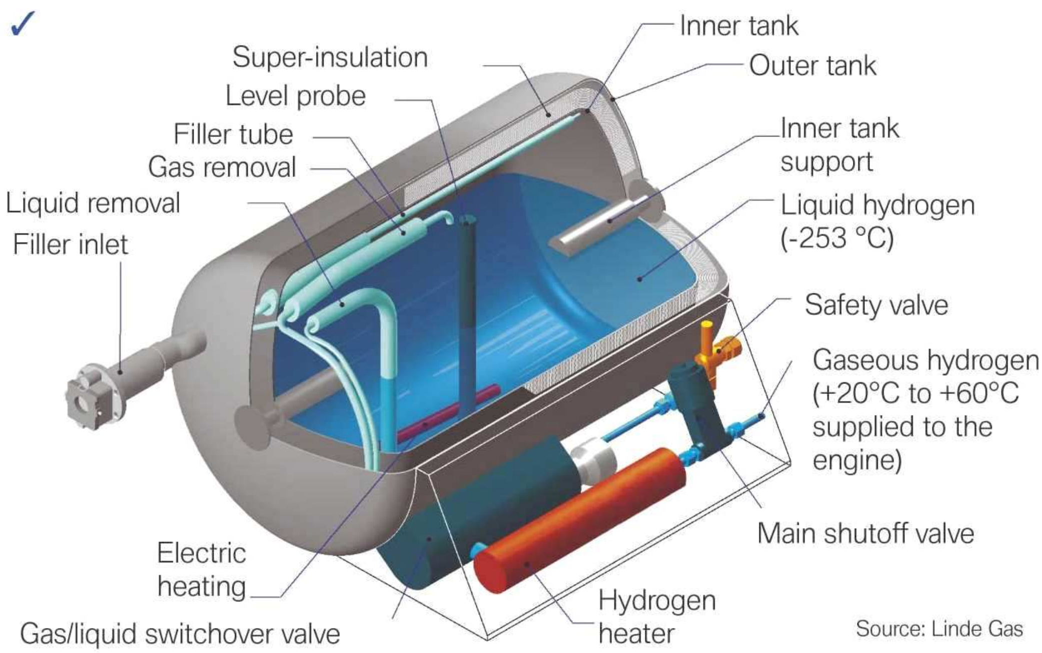

Figure 3-13 – Example of an on-board liquefied hydrogen storage system. Photo courtesy of BMW and Linde.

3.3.2.3 Metal Hydride Fuel Tanks

Metal hydride storage technology is based on reversible chemical reactions that occur between hydrogen and certain metals. During refueling, the metal is “charged” with hydrogen, which bonds with the metal to form the hydride. The charging process produces heat. To discharge the hydrogen, heat is applied to the system. Hydride research and development (R&D) is directed toward identifying systems with high hydrogen capacity when operating within a manageable temperature range. Current emphasis is on a class of complex metal hydrides called alanates.

Metal hydride storage systems consist of the metal (usually a powder form) contained in a pressure vessel (e.g., 1,000 psi). The vessel also contains heat exchange elements, and parts of the heat exchange system that are external to the fuel tank. Current metal hydride storage systems are much smaller than compressed hydrogen systems and slightly larger than liquid hydrogen systems with equivalent energy. These systems are heavier than both compressed and liquid hydrogen systems. ECD Ovonics is preparing to place vehicles with hydride storage systems in the South Coast Air Quality Management District (SCAQMD) fleet demonstrations.

3.3.2.4 Summary of Hydrogen Fuel Storage Systems

Considerable R&D efforts involving industry, government, and national laboratories are underway to advance hydrogen storage technologies. In July 2003, the United States Department of Energy (U.S. DOE) issued a “Grand Challenge” to the scientific community to solicit applications for advancement of hydrogen storage materials and technologies. These solicitations could provide up to $150 million in funds by 2009.[38]

[38] U.S. Department of Energy, National Renewable Energy Laboratory, "NREL Scientists Take On Hydrogen Storage," accessed online at http://www.nrel.gov/features/10-03_hydrogen_storage.html, 3/6/05.

4.0 Key Findings of the Blueprint Plan

This section summarizes the points of agreement reached by the Advisory Panel on a broad range of issue areas and key findings from the detailed work performed by the five Topic Teams. Overarching findings are that investment in hydrogen for California is manageable, but the CA H2 Net should be deployed in multiple phases. Details are provided about the need to build upon existing progress in California, through a "Phase 1" effort that should deploy additional hydrogen fueling stations in close coordination with rising demand for hydrogen. By 2010, a network of 50 to 100 hydrogen stations is achievable and needed to fuel California's growing populations of hydrogen-fueled vehicles and other products (e.g., stationary fuel cells). Biennial technology reviews should be a key to assessing commercial readiness for additional station deployments. The objective should be to achieve a statewide network of 250 hydrogen stations in Phase 2, with hydrogen usage at the stations steadily increasing into Phase 3 and beyond.

4.1 Points of Consensus from the Advisory Panel

Members of the Advisory Panel represented a diverse group of private- and public-sector stakeholders having many interests in the commercialization of hydrogen fuel and hydrogen-fueled products. They were asked to provide guidance and input to the work of the five Topic Teams. Given the Panel's diverse make up, it is significant that members were able to reach agreement on a broad range of issue areas, including:

- The CA H2 Net will continue to put California, its businesses, and universities in a world-class leadership position for the successful introduction of hydrogen technologies.
- The CA H2 Net should use a long-term, multi-phased, sustainable approach to develop hydrogen technologies.
- The CA H2 Net program should make use of existing alternative fuels (e.g. such as natural gas and ethanol) and emerging near and mid-term technologies to expand hydrogen use.
- Investment in hydrogen infrastructure is manageable.
- The CA H2 Net program should investigate a variety of hydrogen production options.
- Hydrogen vehicle introduction will depend on technology and cost readiness as well as consumer acceptance.
- Government fleets, private fleets and "early adopters" should be encouraged to purchase hydrogen vehicles based on technology and cost readiness.
- The CA H2 Net should include energy station concepts.
- The CA H2 Net should achieve a 30 percent reduction in GHG emissions relative to comparable uses of today's fuels and technologies, and utilize 20 percent renewable resources in the production of hydrogen for use in vehicles by 2010.

- The CA H2 Net will best be accomplished by fostering public-private partnerships.

4.2 Advisory Panels' Summary of Overarching Findings

The following section summarizes the overarching implementation strategy of the CA H2 Net. This strategy is based on the Panel's consensus statements and supported by the findings and recommendations of the Topic Teams.

4.2.1 A Multi-Phase Approach to Meet Short- and Long-Term Objectives

A key finding was that California will need to implement the CA H2 Net program in multiple phases, beginning as soon as possible with Phase 1. It will require a long-term commitment and the best efforts of government, industry and consumers alike. In accordance with the findings and conclusions of the Advisory Panel, the recommended program is designed to build hydrogen fueling stations as more hydrogen-fueled vehicles and products are deployed. The objective should be to implement a step-by-step approach with regular reassessments that can manage risks while deploying up to 250 hydrogen stations in California, as envisioned in Executive Order S-7-04.

California is now using and should continue to employ a station build-up strategy, in which fueling stations would initially be clustered in urban areas, with stations distributed between the areas to link them. The urban stations should initially be located in the San Francisco Bay Area – Sacramento regions and the Los Angeles – San Diego regions. In this way consumers can freely travel within these urban areas and commute between the two. This approach will maximize the number of Californians who have access to hydrogen fuel. Table 4-1 provides an overview of the three recommended phases, in terms of types and estimated numbers of hydrogen end-use applications. This is followed by a description of Phase 1 and a brief overview for Phases 2 and 3.

Table 3-1. Estimated Numbers of Hydrogen Products and Stations by Phase

Type of Hydrogen-Fueled Vehicle or Product	Number of Units Targeted / Estimated for Deployment, by Phase		
	Phase 1: 50 to 100 Stations	**Phase 2: 250 Stations (w/ Initial Lower Usage)**	**Phase 3: 250 Stations (w/ Expanded Usage)**
Light-Duty FCVs & H2ICEVs from Major Manufacturers	2,000	10,000	20,000
Heavy-Duty FCVs or H2ICEVs	10	100	300
Stationary and Off-road Vehicle Applications	5	60	400
FCV = Fuel Cell Vehicle H2ICEV = Internal Combustion Engine Vehicle			

4.2.2 Description of Phase 1

The goal for Phase 1 is establishment of a network of 50 to 100 stations in California. Currently there are 39 stations that are either existing or planned for completion in the next two years. Therefore, the efforts of Phase 1 should focus on building 11 to 61 additional hydrogen stations in California. By 2010, this will result in a statewide network of 50 to 100 hydrogen fueling stations that should be located in a manner to maximize hydrogen usage ("throughput," or volume dispensed). This is necessary to establish a network broad enough to support many small fleets. Public access to a station network allows fleet vehicles to be used in a broad urban area without being limited by driving range.

The actual number of stations, within this range, should depend on the rate of introduction of hydrogen-fueled vehicles. These Phase 1 stations should utilize a mix of hydrogen-production technologies that can be evaluated in real-world use by energy companies to assess commercial viability. To the maximum extent practicable, renewable energy sources should be used to produce the hydrogen.

The numbers and locations of stations in Phase 1 are designed to fuel up to 2,000 light-duty vehicles and 10 heavy-duty vehicles. The estimate of the number of vehicles was based on figures provided by members of the California Fuel Cell Partnership and individual manufacturers. In addition, the California Stationary Fuel Cell Collaborative estimated that energy stations could be deployed during Phase 1.

Phase 1 stations will primarily serve fleet vehicles rather than individual consumers. Early Phase 1 hydrogen vehicles are most likely to be placed within fleets owned and operated by the state of California, other government agencies, and private companies with vested interests in hydrogen vehicles. Phase 1 progress and results should be reviewed every two years to assess the progress of hydrogen technologies.

For illustration purposes, placement of fueling stations has been mapped in Figure 4-1(Northern California) and 4-2 (Southern California) for the first phase of the CA H2 Net. The Northern California map shows nine existing or currently planned hydrogen stations (red dots), and ten additional stations (black dots) as they might be sited in the Bay Area or Sacramento under Phase 1 of the CA H2 Net. The Southern California Map shows 21 existing or currently planned stations in the Los Angeles area, and ten additional stations as they might be sited in Phase 1. Together, these two maps illustrate a minimum 50-station network for the major population centers of Northern and Southern California. Additional stations, up to 100, would be sited based on projected demand for hydrogen-fueled vehicles and linkage between urban areas. Some of the Phase 1 hydrogen stations should include energy stations.

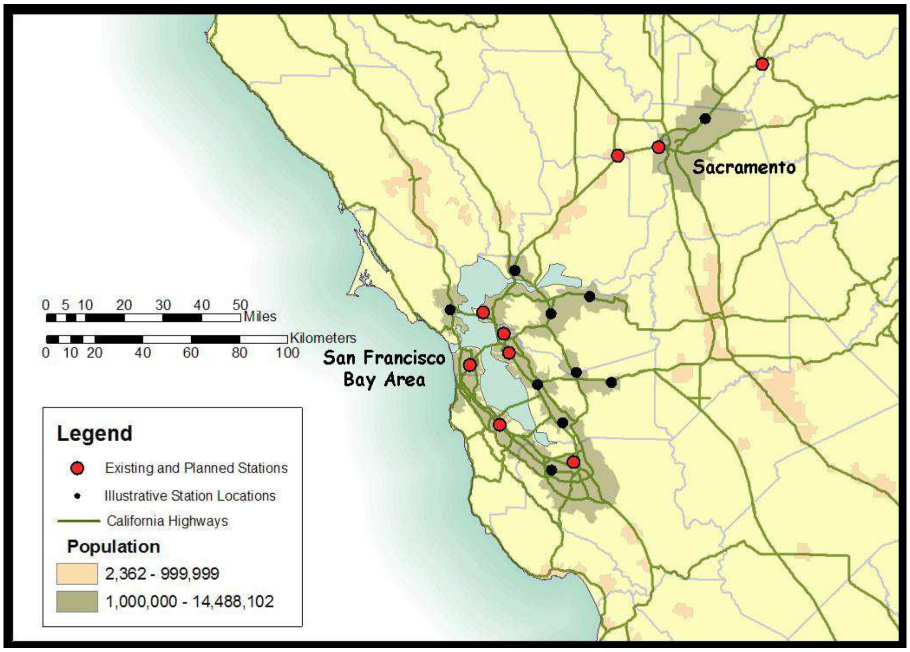

Figure 4-1 – Example station locations for Phase 1 in Northern California based on population density and existing gasoline stations [39]

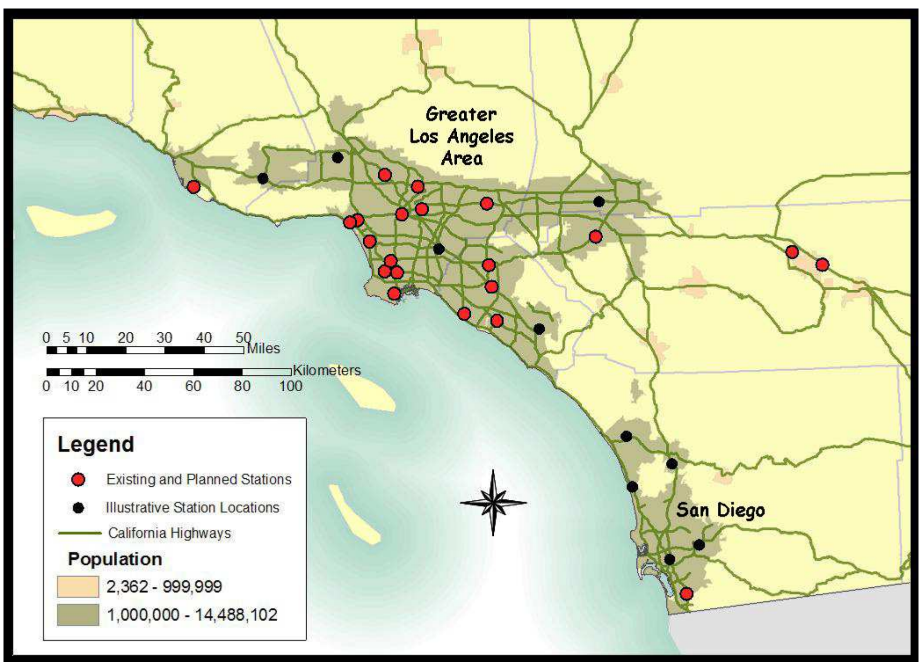

Figure 4-2 – Example station locations for Phase 1 in Southern California based on population density and existing gasoline stations[40]

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[39] These maps are meant to illustrate station placements rather than show actual station locations. These maps show a combination of actual and hypothetical placements for planned and yet to be planned sites. Only 30 of the currently estimated 39 existing station are shown. Many of the currently planned station sites are confidential.

[40]See previous footnote.

4.2.3 Description of Phases 2 and 3

Assuming sufficient progress with vehicle deployments and other milestones in Phase 1, as judged by the results of regular reviews, it is anticipated that a total network of 250 fueling stations will be completed by the end of Phase 2, for increasing utilization into Phase 3 and beyond. For illustration purposes, placement of these fueling stations for Northern and Southern California is shown in figures 4-3 and 4-4, below. In Phase 2, these stations will serve approximately 10,000 vehicles – a similar vehicle-to-station ratio as Phase 1, but with expanded numbers of vehicles in broader applications, and an expansion in energy station deployments. Also in this time frame, home fueling stations for hydrogen vehicles (similar to home fueling now being commercialized for natural gas vehicles) may begin to play an enabling role for the CA H2 Net. These can be small-scale residential energy stations that allow homeowners to fuel their vehicles while also powering, heating or cooling their homes.

In Phase 3, volumes of hydrogen dispensed at these 250 hydrogen stations should be increased significantly by expanding the fleet to approximately 20,000 vehicles. This higher Phase 3 ratio of vehicles to stations (80:1) is indicative of a doubling in "capacity utilization" for the total station network. Phase 3 also assumes an expanded role for energy stations.

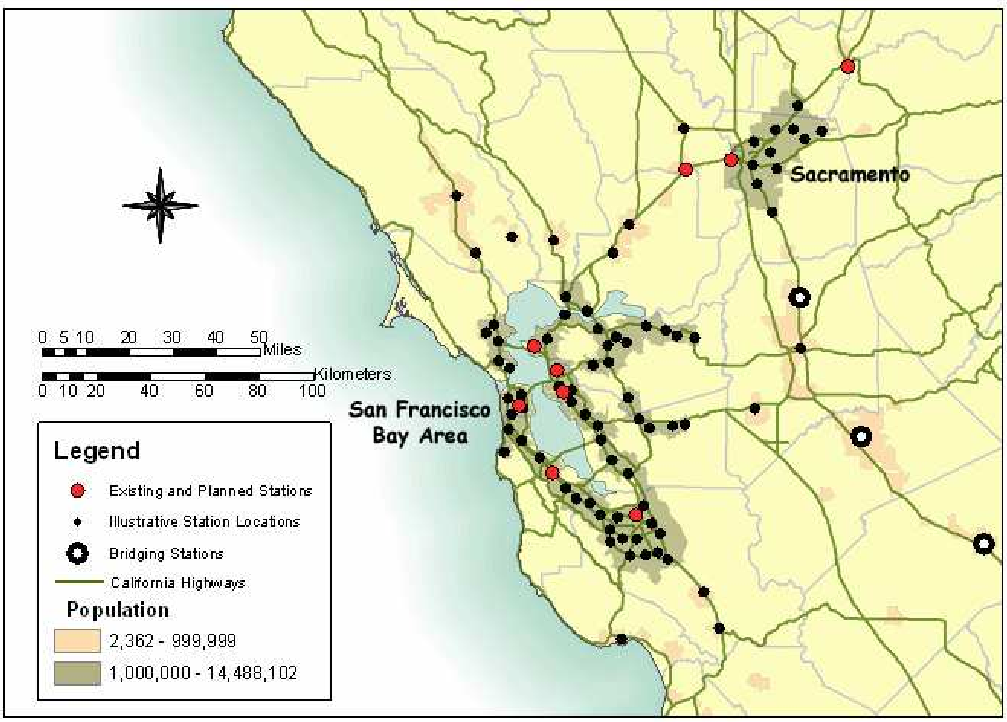

Figure 4-4 – Example of Phase 2 stations in Northern California

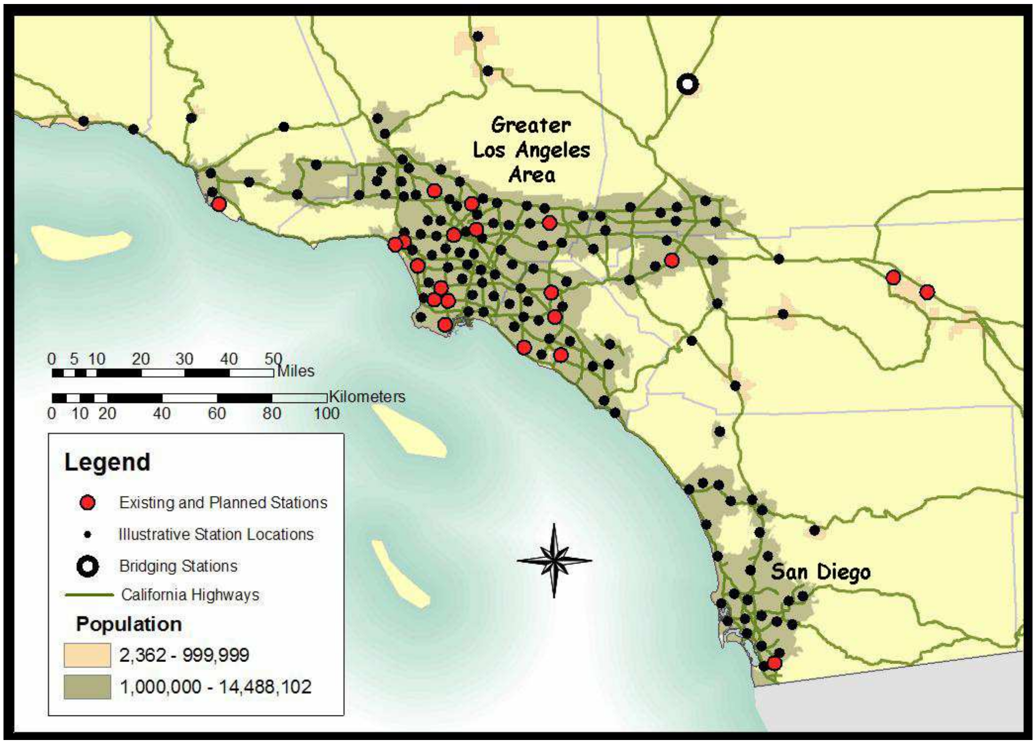

Figure 4-4 – Example of Phase 2 stations in Southern California

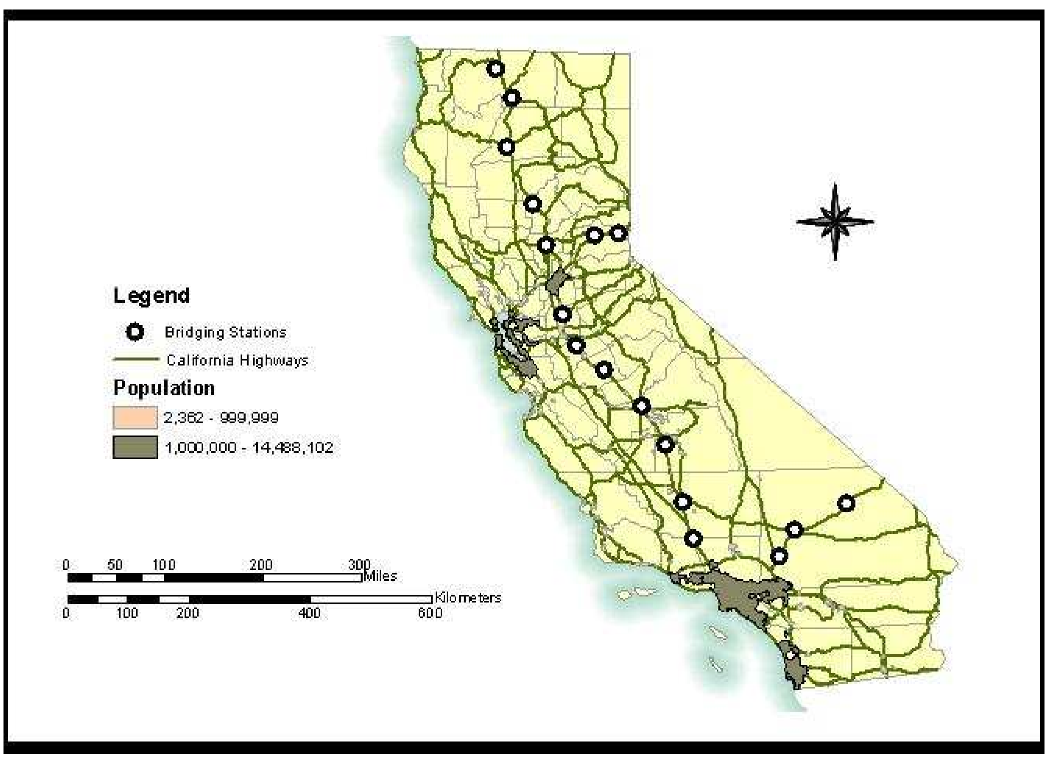

Figure 4-5 – Example of "Bridging" Hydrogen Stations That Would Join California's Major Urban Areas.

As illustrated in the maps above, early stage development of all hydrogen stations will focus on regional network clusters in key northern and southern California urban areas.

These regional clusters would ultimately be bridged to form the comprehensive state network described in Executive Order S-7-04. Figure 4-5 illustrates a statewide bridging network of 17 stations along California's interstate highways.

4.2.4 "Bridging" Fuels and Technologies Can Advance the CA H2 Net

As pointed out in the Societal Benefits Team findings, the CA H2 Net is part of a broader energy and environmental strategy for California. This strategy includes a portfolio of other vehicle technologies and fuels, in addition to hydrogen vehicles and infrastructure. California has long been a world leader in the development and deployment of clean-burning alternative fuels, low- / zero-emission propulsion technologies, and their corresponding infrastructure technologies. Many of these are already playing a key role in California's transportation sector to displace petroleum usage and provide very significant air quality benefits. Moreover, many of the fuel / technology combinations are considered to be "bridging technologies" to hydrogen vehicles and fueling stations, because they address many of the same issues and entail the same or related technologies. Examples of bridging technologies include, but are not limited to, natural gas vehicles and fueling stations, vehicles using hydrogen / methane blends and their fueling infrastructure, electric vehicles and propulsion systems, on-board fuel storage systems, and energy storage devices such as batteries and ultracapacitors. Past successes and current programs to support such fuels and technologies clearly benefit the longer-term prospects for hydrogen vehicles and fueling stations.

As an example, efforts in California to develop and deploy natural gas vehicles (NGVs) and related technologies are helping to expedite commercially sustainable hydrogen vehicle markets. Many existing capital, institutional, educational and organizational investments involving NGVs and natural gas fueling stations are directly or indirectly applicable to the hydrogen technologies that will be needed under the CA H2 Net. Similarly, many "lessons learned" from NGVs and natural gas directly apply to fuel cell vehicles and hydrogen.

Specific examples of how natural gas and NGV technologies are considered "bridging" to hydrogen are highlighted below.

- Natural gas is the leading feedstock for hydrogen production in the U.S. today. Many of the first fueling stations along the CA H2 Net will likely produce hydrogen onsite by reforming pipeline natural gas. Some of these will be advanced energy stations with stationary fuel cell systems.

- Whether it is used in stationary fuel cells or as a feedstock for hydrogen production, natural gas can be made from renewable resources such as landfill or digester gases ("biogases").

- Today's users of NGVs are becoming acclimated to the use of gaseous fueling systems. This will help prepare and educate the motoring public for dispensing gaseous hydrogen.

- Until major breakthroughs in hydrogen storage technologies are realized, hydrogen will most likely be stored on-board vehicles as a compressed gas or a cryogenic liquid. Progress is well underway, as today's prototype hydrogen vehicles are able to use existing tank technology for compressed natural gas (CNG) or liquefied natural gas (LNG) vehicles as base technologies for hydrogen storage.

- Several companies that make NGV tanks are also designing improved fuel-storage systems for hydrogen vehicles. Some of these companies serve as "Tier 1" suppliers for major automobile manufacturers that market NGVs today, and plan to sell hydrogen vehicles in the future. These types of relationships will become increasingly important as the market for hydrogen vehicles moves into the commercialization phase. Commonality also exists among companies working on fuel management systems for NGVs and hydrogen vehicles.

- Hydrogen can be blended into natural gas to produce a fuel that burns even cleaner and more efficiently than natural gas. Heavy-duty transit buses with moderate engine modifications are already being operated on CNG blended with gaseous hydrogen. SunLine Transit Agency in partnership with Cummins-Westport, U.S. DOE – National Renewable Energy Laboratory and the SCAQMD has demonstrated that a blend of 80% CNG and 20% hydrogen (by volume) significantly reduces NO_x emissions compared to the already low emissions from the same bus operating on CNG fuel alone. SunLine's hydrogen is produced (at least partially) from solar-powered electrolysis, which provides further societal benefits.[41]

4.2.5 Leverage Existing Programs

Numerous hydrogen-related partnerships and programs currently exist in California and across the globe. Many have common goals and objectives to the CA H2 Net, and offer leveraging potential. In one form or another, organizations are working to develop and commercialize hydrogen-fueled vehicles and the corresponding fueling infrastructure. In the United States, these include 1) various California efforts such as the Air Resources Board's low-/zero-emission vehicle regulations and the Energy Commission's hydrogen infrastructure program, 2) local efforts such as the South Coast Air Quality Management District's Technology Advancement Program, 3) federal efforts such as the U.S. DOE's FreedomCAR & Fuel Initiative, and 4) public-private partnerships involving all these parties, such as the California Fuel Cell Partnership. Other organizations, such as the California Stationary Fuel Cell Collaborative, are working to commercialize stationary fuel cell technologies that co-generate electricity and usable thermal energy while consuming or producing hydrogen.

Especially important are the existing programs that can directly impact California's efforts to develop and demonstrate hydrogen vehicles in parallel with deployment of hydrogen fueling infrastructure. Some of the key programs are briefly described below.

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[41] See various Topic Team reports, including the Rollout Strategy Team Report, which contains detailed discussion on the costs and benefits of using natural gas-hydrogen blends.

The California Fuel Cell Partnership – A prominent example is the California Fuel Cell Partnership (CaFCP), which was formed in January 1999 by the California Air Resources Board, the California Energy Commission, and six private-sector companies to commercialize fuel cell vehicles. Over the last five years, the CaFCP has grown into 21 full members and 11 associate members, and has become a unique collaborative of auto manufacturers, energy companies, fuel cell technology companies, and government agencies. Since 2000, CaFCP members have demonstrated 65 light-duty vehicles in California and traveled more than 220,000 miles on California's roads and highways. These vehicles have supported more than 120 outreach events, carrying nearly 12,000 test riders. [42]

In addition to testing numerous types of fuel cell vehicles, the CaFCP is developing hydrogen fueling protocols and "beginning to prepare the California market for this new technology."[43] The CaFCP members cooperatively address technical issues affecting the implementation of fuel cell vehicles and work to educate the public on the benefits of fuel cells. Although the CaFCP targets hydrogen fuel cell vehicle commercialization over a more gradual timeframe, it clearly has goals and objectives that are similar to, and synergistic with, the CA H2 Net. Extensive details can be found on the CaFCP's website (http://www.fuelcellpartnership.org).

California Stationary Fuel Cell Collaborative – The California Stationary Fuel Cell Collaborative (CaSFCC) is an organization of government agencies, stationary fuel cell companies, utilities, universities, environmental groups and other non-government organizations that are combining efforts and resources towards commercialization of stationary fuel cells in California. The mission of this Collaborative is to promote stationary fuel cell commercialization as a means towards reducing or eliminating air pollutants and greenhouse gas emissions, increasing energy efficiency, promoting energy reliability and security, promoting energy diversity, promoting energy independence, and realizing a sustainable energy future. Formed in June of 2001, the Collaborative promotes a wide variety of fuel cell technologies, sizes and applications for installation in California and envisions fuel cell installations pursued by state, local and public organizations as well as private entities. As further described in this report, the CaSFCC has identified opportunities and benefits of (1) energy stations to catalyze and sustain the implementation of CA H2 Net with a business viable enterprise, real estate, and a supporting balance of plant, and (2) high temperature fuel cells to co-generate hydrogen on demand for vehicle refueling in addition to the generation of electricity and usable heat to meet local requirements (e.g., an office building complex).[44] Details can be found at http://www.stationaryfuelcells.org.

U.S. Department of Energy – The federal government is working to deploy hydrogen vehicles and fueling stations, under several efforts that can loosely be called public-private partnerships. For example, in April 2004 under its "Technology Validation" program, the DOE selected five public-private teams to participate in "learning

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[42] The California Fuel Cell Partnership, "Our Mission," from website http://www.fuelcellpartnership.org, accessed November 17, 2004.

[43] Ibid.

[44] The California Stationary Fuel Cell Collaborative, *Position in Support of the California Hydrogen Highway Network*, website (http://www.stationaryfuelcells.org), online September 2004.

demonstrations" that include testing, demonstrating, and validating hydrogen fuel cell vehicles as well as fueling infrastructure. Each validation project includes a comprehensive safety plan; an activity to assist in developing codes and standards; and a comprehensive, integrated education and training campaign. A key objective of these demonstrations will be to assess progress of fuel cell vehicles and hydrogen station technologies towards making commercialization decisions by 2015.[45] In the 2010 timeframe, DOE plans to build approximately 19 more hydrogen stations in California. These will be sited along major interstates and in key urban areas such as San Diego, Los Angeles, San Francisco and Sacramento.[46] Details can be found on the DOE website (www.eere.energy.gov/hydrogenandfuelcells).

The South Coast Air Quality Management District's Technology Advancement Program – SCAQMD's Technology Advancement Program co-sponsors collaborative efforts with the private sector and fellow government agencies to develop, demonstrate and commercialize fuel cell and hydrogen technologies. Most recently, SCAQMD has formed its own collaborative effort involving local municipalities and hydrogen technology developers, in which small fleets of advanced, hybrid-electric vehicles fueled by hydrogen will be deployed throughout Southern California. As many as 35 hybrid-electric Toyota Priuses will be converted to operate on hydrogen, using two types of on-board hydrogen storage technologies (compressed hydrogen and metal hydrides). These advanced H2ICEVs will be used by five different local cities. To fuel these and other hydrogen vehicles being deployed in the greater Los Angeles area, SCAQMD is cost sharing at least 13 hydrogen fueling stations. Several of these are already dispensing hydrogen to small fleets of prototype fuel cell and ICE vehicles. Details can be found on SCAQMD's website (www.aqmd.gov).

Activities Outside the United States – In Canada, Japan and Europe, important programs are underway to deploy hydrogen fueling station networks to support commercialization programs for hydrogen-fueled vehicles and other devices. Canada's programs are described online at: http://www.nrc-cnrc.gc.ca/highlights/0405hydrogen_e.html. Details about Japan's programs can be found online at http://www.fcdic.com/eng/news/200411.html. Details about European programs can be found at the Fuel Cell Europe website (http://www.fuelcellmarkets.com/home-fcm.fcm?subsite=1&language=1).

Other States – At least thirteen states either have funding mechanisms in place or proposed for hydrogen projects and most states have University researchers working on hydrogen related technologies. The Colorado Fuel Cell Research Center has leveraged $2 million in public funding to develop a project worth over $12 million. Florida presently has proposed legislation worth over $15 million in funding and tax credits for hydrogen projects. Minnesota has a legislative proposal worth $6 million in bonds that would be used to build a wind-to hydrogen project. Even a smaller state like Hawaii has been investing in hydrogen since 1983.

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[45] U.S. Department of Energy, Energy Efficiency and Renewable Energy office, "DOE Hydrogen Fleet and Infrastructure Demonstration," accessed online at http://www.eere.energy.gov/hydrogenandfuelcells, November 17, 2004.

[46] Based on information provided to TIAX by Margo Melendez, National Renewable Energy Laboratory, October 2004.

These various programs and others (see Topic Team reports) represent important existing activities to commercialize hydrogen-fueled vehicles and products, and deploy the fueling stations needed to support them. *An important finding of this Blueprint Plan is that implementation of the CA H2 Net can be coordinated with existing programs.* This synergy extends well beyond programs involving research, development and demonstration. For example, joint or similar policies could be adopted among states to ease siting and fueling concerns, as well as spur increased vehicle production.

4.2.6 The Need for Government to Share Costs and Risks

As described in Section 3, implementation of hydrogen transportation and a hydrogen economy entails many challenges. The investment by auto manufactures and the U.S. Department of Energy to solve these challenges demonstrates that there is a collective belief that they will be overcome. The CA H2 Net is an important part of making California the place to demonstrate and advance the vehicle and infrastructure technology so that we realize the benefits of success as quickly as possible.

The current pace to develop hydrogen-fueled vehicles and products is hindered by the need to solve the so-called "chicken-or-egg" question: which should come first, commercialization of vehicles that run on hydrogen, or building of fueling stations that dispense it? Who should take the initial risk with expanded investments: hydrogen producers or vehicle manufacturers? What is the appropriate role of the government? Past experience with clean, alternative fuels in California has helped answer these questions: the early risks must be shared. Because many of the fundamental benefits of the CA H2 Net – including reducing pollution and petroleum dependence – are long-term public benefits, they do not translate readily into private investment inducements today. According to the Economy Team, the view from the financial markets is that the *private* gains associated with the CA H2 Net lie too far into the future to attract purely private financing. Therefore, public policy, political leadership and public financing intervention will be essential for building a strong and viable CA H2 Net.

4.3 Summary of Topic Team Findings

Five working groups or "Topic Teams" were established to address specific issues and challenges associated with developing the CA H2 Net. Each Topic Team met regularly to perform technical and policy analyses and develop topic-specific recommendations for the Blueprint. The 20-member Advisory Panel provided guidance to the five Topic Teams over the course of six meetings. The end result and deliverables for this entire process is this Blueprint Plan and the five individual Topic Team reports.

Much of the work performed by the Topic Teams was done in parallel. To help focus the efforts of the Topic Teams, the Advisory Panel suggested a "scenario" approach that identified rough estimates for the numbers of hydrogen-fueled vehicles (light-, medium-, heavy-duty vehicles and off-road applications) and devices (stationary fuel cells including energy stations) that might be deployed in the timeframe of the CA H2 Net. These "unifying scenarios" were used to estimate the CA H2 Net's costs as well as environmental and energy benefits within the 2010 timeframe. The results of these scenarios were later transformed into the three implementation phases further described in this report. The phases that emerged are not constrained to 2010. Movement from Phase 1 to subsequent phases in the CA H2 Net, as further described in this document, are seen as dependent on adequate development of technology and reduction in per-vehicle or per-application costs.

IMPORTANT NOTE: Extensive information about the work performed by each Topic Team, and all the related findings and recommendations, are contained in the individual Topic Team reports.

4.3.1 Rollout Strategy Team

4.3.1.1 Mission

The Rollout Strategy Team's mission was to assess hydrogen technology and industry readiness as well as identify criteria for siting stations to implement and grow a hydrogen highway network in California. The plan also included strategies to accelerate the commercialization of hydrogen as a fuel for vehicle and power generation, including the use of energy stations. The rollout strategy employed the multi-phased approach with the ultimate goal of achieving a self-sustaining hydrogen industry that can provide increasing volumes of fuel for California's transportation sector.

In an effort to achieve the team's mission, the following four subgroups were formed: (1) Production and Delivery, (2) Applications, (3) Sites, and (4) Commercialization. The Production and Delivery subteam addressed the availability, commercial readiness, barriers, environmental considerations, and other issues regarding options for production and delivery of hydrogen. The Applications subteam was responsible for understanding the same types of issues with respect to vehicles, stationary fuel cells, and energy stations. The Sites subteam developed a set of criteria for siting hydrogen fueling stations, which included leveraging existing vehicle fueling or hydrogen facilities, securing champions for initial stations, and identifying locations where distributed generation could be used in conjunction with fueling. The Commercialization subteam identified barriers and actions needed to accelerate the commercialization of hydrogen vehicles and evaluated past efforts to commercialize alternative-fuel vehicles.

4.3.1.2 Summary of Findings

The Rollout Strategy Team's major findings covered several topics. First, the Production and Delivery subgroup evaluated the various options for hydrogen production and delivery in terms of availability/industry readiness, technical and economic barriers, and environmental impacts and considerations. The focus was on production options that can eventually assure energy security and clean air for California. Both centralized and distributed production of hydrogen were considered in the comprehensive analysis. The various production options evaluated were:

- Electrolysis
- Reforming (principally of methane and methanol)
- Photobiological and photoelectrochemical
- Biofermentation
- Pyrolysis and gasification of biomass and coal
- High temperature thermochemical
- Membranes

The Team found that Phase 1 technologies of reforming (both centralized and distributed) and electrolysis are likely to contribute most significantly to the early stage development of the CA H2 Net because these established technologies leverage the existing electricity grid and natural gas pipeline infrastructure. Delivery options include truck, mobile refuelers, and to a limited extent, pipeline.

The Applications subgroup studied potential applications for hydrogen. The subgroup found that the main drivers for hydrogen applications are fuel cells and ICE vehicles, although there are a wide variety of other hydrogen applications.

The Sites subgroup found that successful deployment of hydrogen vehicles in California requires a network of hydrogen fueling stations placed in strategic locations for maximum utilization. This would enable regional (inter-city), inter-regional, and ultimately inter-state travel.

The subgroup found that optimal locations of hydrogen fueling stations should (1) optimize network development and reliability; (2) maximize the number of stations accessible to the appropriate users, (3) leverage the early distributed generation market, and (4) operate with a high percentage of fuel utilization, demonstrating maximum hydrogen fuel throughput. An additional finding was that seeking locations that offer synergies (e.g., co-location with compressed or liquefied natural gas (CNG or LNG) stations) will reduce costs or advance other state energy goals.

The Sites subgroup developed screening criteria that can be used to guide final site selections. They found that two key success factors should be considered in establishing a site. The first was to ensure sufficient utilization by deploying hydrogen-fueled vehicles and/or an energy station at the station location. The second success factor was to ensure that the site host partner has a strong commitment to the station's sustainability. The key here was for the host partner to have demonstrated long-term, top-down management support. Further, it was important that the host partner have a local on-site champion. Through this combination, the organization should be able to overcome the numerous challenges of introducing a new fuel and technology. These challenges included station funding, insurance underwriting, vehicle technology attractiveness, vehicle costs, facility modifications, fuel costs, and station access. See the Rollout Strategy Team Report for further discussion of siting challenges.

A total of 19 different types of host fleets and potential locations were identified. A comprehensive set of screening criteria was also established.

Table shows the types of parameters that were considered in developing criteria to help choose potential sites and projects.

Table 4-2 – Site Location Considerations

Considerations for Site Location	Attributes to Assess
Ability to serve maximum number of users	Proximity to nearby fleets, public access station opportunity, proximity to stationary or other H2 users
Strategic location	Support of regional, inter-regional, or inter-state travel, provider of private and/or public access, high volume location
Safety	Proximity to schools, hospitals or other sensitive locations, proximity to earthquake faults
Economic factors	Proximity to existing or planned merchant hydrogen source, anticipated level of utilization now and in future
Experience with gaseous and alternative fuels	Current CNG operations, experience working with gaseous fueled fleets and vehicles
Ease of Logistics	Adequate space for hydrogen/gaseous fuel equipment, suitability of the site for various types of forecourt designs, permanence of proposed site, required utilities (water, power, natural gas) at the facilities, ease of incorporation of renewable energy equipment, proximity to renewable energy sources, site use restrictions, support of local Authority having Jurisdiction (AHJ), neighborhood, and utilities, potential for incentives
Additional distributed generation considerations	On-site electric or thermal loads to utilize cogeneration, potential for "over the fence" sales of electricity

Based on these types of parameters, the subgroup found that station development will initially need to leverage a fleet-based strategy, with transition considerations toward a full retail market in the later phases of the CA H2 Net.

Early station placement should be based on the "anchor tenant" model (see Glossary), which is discussed further in the Rollout Strategy Team Report. Combined with existing, planned, and anticipated hydrogen stations, early stage development should focus on regional network clusters in San Diego, the Los Angeles Basin, Sacramento, and San Francisco. Strategic locations in the San Joaquin Valley should also be considered. Ultimately, these regional clusters should be bridged to form a comprehensive state network. Further discussion and maps are provided in Section 4.2.3 about how potential growth in station placement is envisioned to spread stations throughout Northern and Southern California and create a statewide bridge during successive phases of the CA H2 Net.

The Commercialization subgroup found that accelerating commercialization of hydrogen technologies and infrastructure would support the implementation of the CA H2 Net. The subgroup developed a list of recommended activities that will help accelerate commercialization. They are encompassed in the recommendations discussed in Section 6.

4.3.2 Societal Benefits Team

4.3.2.1 Mission

The mission of the Societal Benefits Topic Team was two-fold. First, the team quantified the societal impacts of various methods of hydrogen production and vehicle technologies that are expected to be commercially viable by 2010. Second, the team considered policies that could successfully incentivize those fuel production and hydrogen vehicle technologies that provide the greatest societal benefits. These analyses and determinations were devised by team members, including approximately 20 scientists, engineers, business leaders, and policymakers from California state government, national laboratories, universities, public utilities and auto manufacturers.

Although hydrogen has the potential to provide significant environmental benefits, the degree to which those benefits are realized depends entirely on how the hydrogen is produced and then used in vehicle and other applications. The Societal Benefits team approached its mission by developing methods to rank the impacts of hydrogen production, distribution, and consumption methods – collectively referred to as "pathways" – based on their environmental impacts. Impacts on greenhouse gas (GHG) emissions, criteria pollutant emissions, and energy efficiency were determined.

The environmental and energy diversification benefits for hydrogen vehicles were modeled based on the station mix described in full detail in the Societal Benefits Team Report. The team analyzed options for renewable and low-greenhouse gas emission hydrogen production, and assessed policy options to incentivize a CA H2 Net that encouraged the greatest societal benefits. Such benefits can be measured by comparative reductions in GHGs, criteria pollutants, petroleum dependency, and other health and ecosystem impacts. Emissions and energy modeling of the CA H2 Net showed that it was possible to reach specific goals for emissions reductions and resource usage.

4.3.2.2 Summary of Findings

Source-to-Wheel Emissions and Energy Analyses

To fully assess the environmental impacts of any fuel pathway and vehicle technology combination, it was necessary to analyze the processes from the beginning of fuel production to the operation of the vehicle. This type of assessment, referred to here as "source-to-wheel" analysis,[47] was an essential tool for comparing different fuels and vehicles under the same set of parameters. For each hydrogen fuel production pathway and vehicle type, the Societal Benefits team calculated the source-to-wheels GHG, criteria pollutant emissions, and energy consumption. This section presents the source-to-wheels emissions and energy consumption for several light-duty hydrogen pathways and compares them to the emissions and energy consumption for projected average 2010 model year gasoline vehicles (including conventional vehicles, hybrids, and partial zero emission vehicles (PZEVs)).

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[47] This is often referred to as "well-to-wheels" analysis. This document uses the term "source-to-wheels" due to the fact that not all hydrogen production involves initial pumping of energy resources from oil or gas wells. Topic Team reports use the term "well-to-wheels." Source-to-wheels is more precise, but the two terms are interchangeable.

The emissions and energy use analyses for each pathway depended on assumptions about vehicle energy consumption because this determines how much pollution comes from the fuel production and distribution processes. The Societal Benefits Team chose to use a vehicle energy consumption metric that measures the improvement in fuel economy for any hydrogen vehicle as compared to any gasoline vehicle of the same platform. This allows for apples-to-apples comparisons of vehicles even though both hybrid and non-hybrid versions of hydrogen and gasoline vehicles may exist in 2010. The Team Report provides further details about the vehicle energy consumption metrics.

The components of source-to-wheel emissions are briefly described as follows:

- ***Fuel Production and Distribution.*** There is a range of potential emissions from the production and distribution of hydrogen, depending on the production method and whether it is transported or used on-site. This is also the case for gasoline and other transportation fuels.

- ***Vehicle Emissions***. Different types of hydrogen vehicles have varying profiles for the types and amounts of pollutants they emit. Hydrogen fuel cell vehicles have zero emissions of criteria pollutants and GHGs (with the exception of air conditioner refrigerant). Hydrogen ICEVs emit small amounts of oxides of nitrogen (NOx) and particulate matter (PM) but no GHGs (except for air conditioner refrigerant). Gasoline vehicles emit varying levels of criteria pollutants and GHGs.

Production methods depicted in the series of figures below represent the ranges of emissions for pathways likely to be available in the 2010 timeframe. These figures are representative of light-duty vehicles only. Heavy-duty vehicles and stationary applications (particularly energy stations, which have strong potential to provide public health and environmental benefits) are discussed in further detail in the Societal Benefits Topic Team Report.

Greenhouse Gas Emissions

The Societal Benefits Team found that the CA H2 Net has the potential to reduce GHG emission reductions by 2010 and beyond. Different fuel production pathways result in different GHG emissions. Ultimately, hydrogen fuel cell vehicles using hydrogen produced from renewable resources would make a near-zero emission transportation sector possible (source-to-wheels basis). However, in the interim, some technologies that emit varying amounts of GHGs will be employed.

The efficiency of the vehicle using hydrogen must be considered to understand the impacts on GHG emissions. This is because, although hydrogen FCVs and ICEVs have no GHG emissions, more hydrogen is needed to drive an H2ICEV for a given distance than a fuel cell vehicle. Those varying fuel consumption rates affect how much fuel must be produced, and therefore affect how much GHG emissions are generated upstream as a result of hydrogen fuel production. For example, consuming hydrogen produced from natural gas in a fuel cell vehicle provides significant overall GHG benefits compared to gasoline; yet, when that hydrogen is used in an H2ICEV, GHG emissions are very close to the GHG emissions generated if that vehicle were to run on gasoline.

Figure depicts source-to-wheel (STW) GHG emissions from both H2ICE vehicles and fuel cell vehicles based on different fuel production pathways. STW GHG emissions for a gasoline vehicle are also shown for comparison. Among the pathways in this figure, the lowest STW GHG emissions occur when a fuel cell vehicle runs on hydrogen produced via electrolysis, with the electrolysis powered by renewable energy. In this instance, GHG emissions are near zero and significantly lower than comparable gasoline vehicles. By contrast, STW GHG emissions are highest when an H2ICE vehicle uses hydrogen produced by California grid-powered electrolysis. In this instance, GHG emissions are higher than gasoline vehicles.

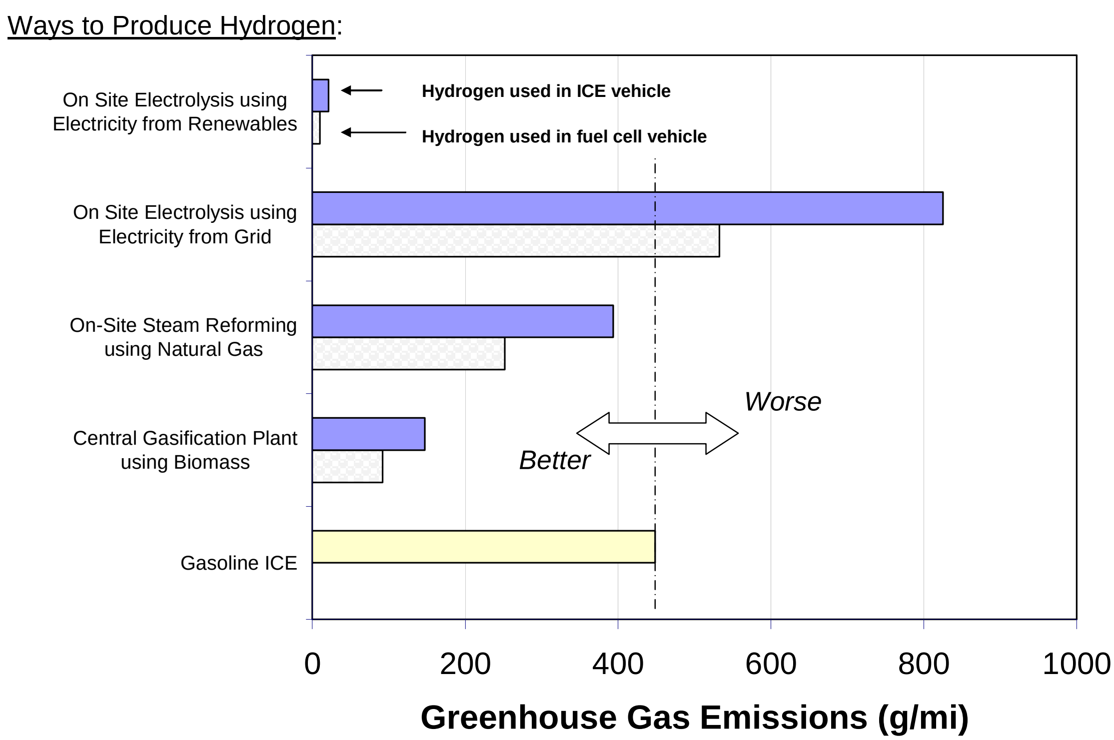

Figure 4-6 – Source-to-Wheels (STW) GHG Emissions

Criteria and Toxic Pollutant Emissions

Criteria pollutant emissions – oxides of nitrogen (Nox), particulate matter (PM), reactive organic gases (ROG), and carbon monoxide (CO) – from hydrogen production and use in vehicles are extremely low. In almost every case these emissions are well below those from gasoline production and use in gasoline vehicles. However, there are exceptions. The figures below show source-to-wheel (STW) emissions of specific criteria pollutants.

Figure depicts the STW NOx emissions from both H2ICE vehicles and hydrogen fuel cell vehicles relative to a comparable gasoline (ICE) vehicle. As indicated in Figure 4-7, NOx emissions from fuel cell vehicles are much lower than gasoline vehicles. However, ICE vehicles using hydrogen produced by electrolysis or on-site steam reformation only achieve small reductions over the gasoline ICE vehicle.

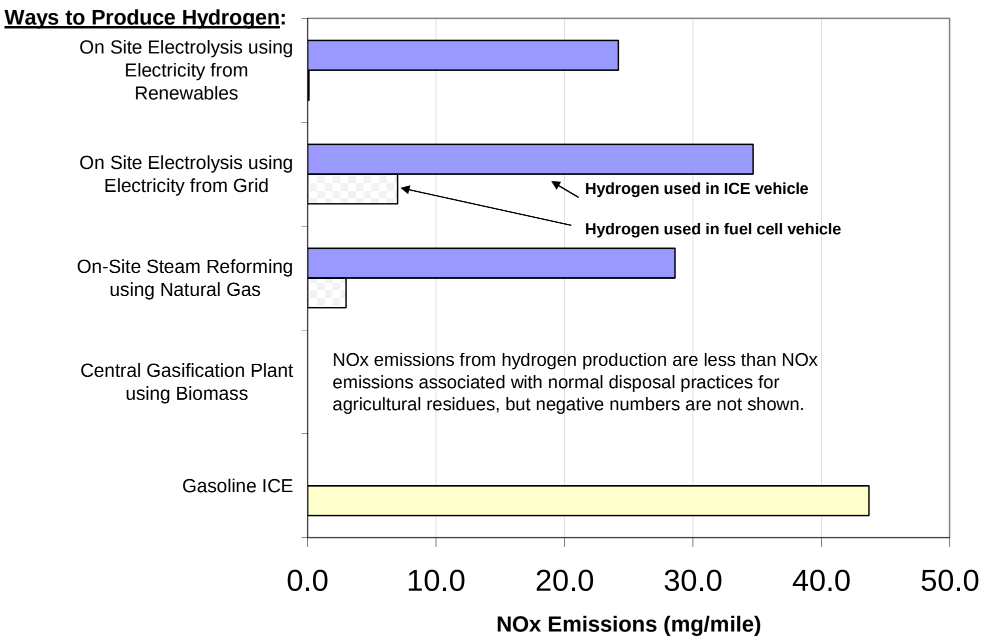

Figure 4-7 – Source-to-Wheels NOx Emissions

Figure depicts the source-to-wheel PM emissions from both H2ICE vehicles and hydrogen FCVs as compared to the gasoline vehicle baseline. As shown in Figure 4-8, hydrogen produced from grid electrolysis has the potential to increase PM emissions. However, it is important to note that most urban areas in California do not permit increases in criteria pollutant emissions from stationary sources and would therefore require mitigation of significant emissions from a hydrogen production facility in the form of offsets and/or maximum emission controls. All other hydrogen production methods would result in decreased PM emissions relative to gasoline vehicles.

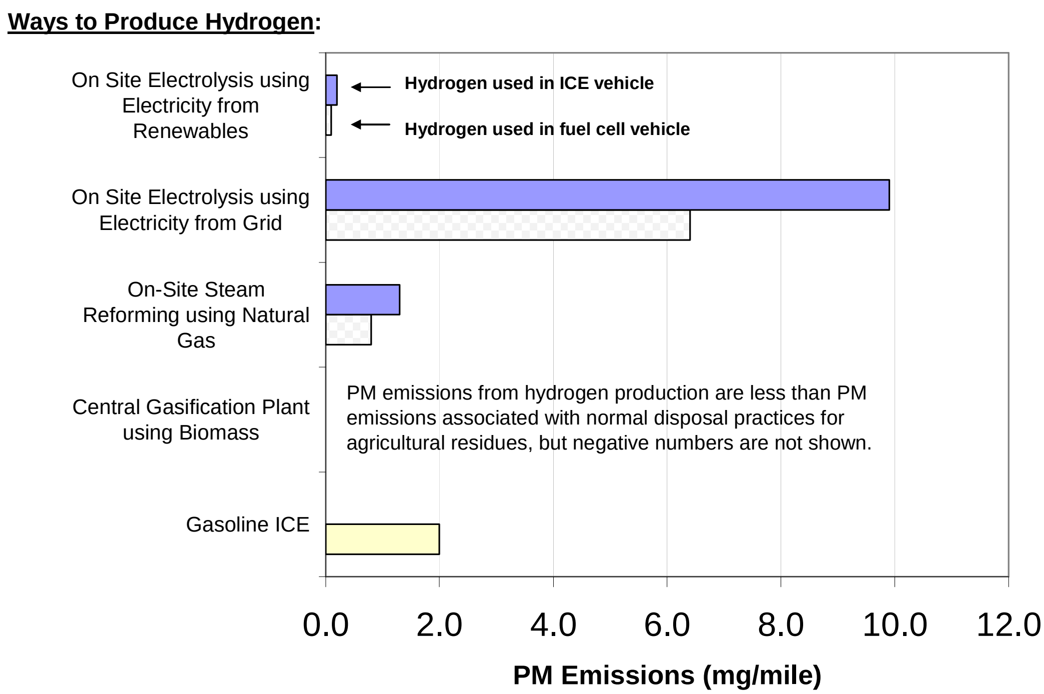

Figure 4-8 – Source-to-Wheels PM Emissions

Figure depicts the source-to-wheel ROG emissions from both H2ICE vehicles and fuel cell vehicles as compared to the baseline gasoline vehicle. All of the hydrogen production methods shown result in significantly decreased ROG emissions relative to conventional vehicles. Toxic air emissions are a component of the ROG emissions and, therefore, there will likely be a concurrent decrease in air toxics as a result of hydrogen vehicle deployment under the CA H2 Net.

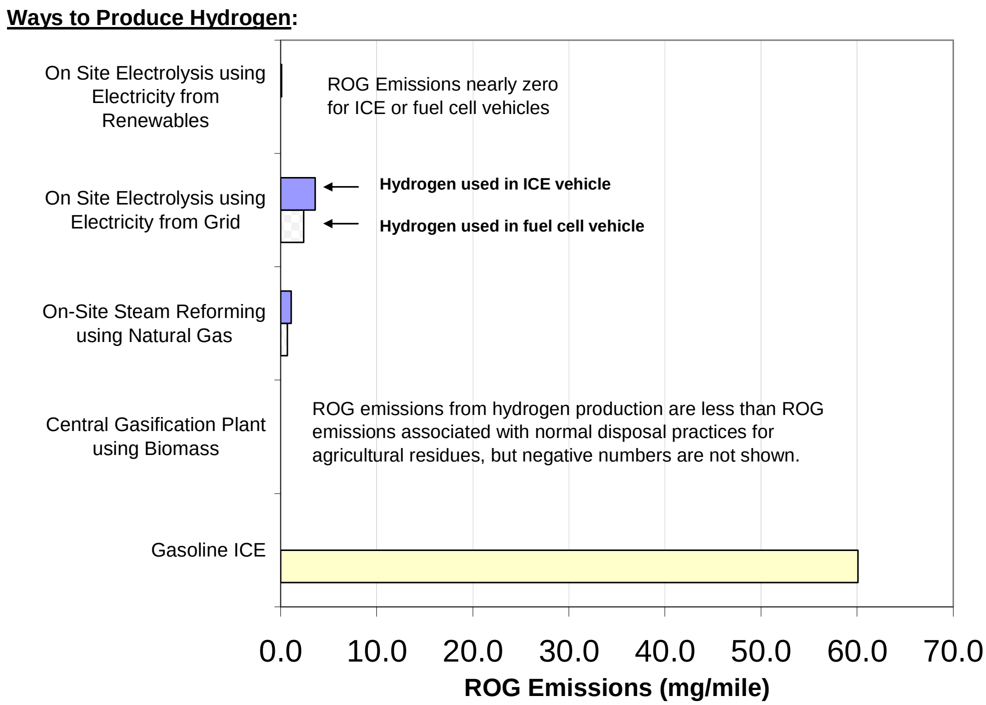

Figure 4-9 – Source-to-Wheels ROG Emissions

Figure depicts the source-to-wheel CO emissions from both H2ICE vehicles and fuel cell vehicles as compared to a gasoline vehicle. All hydrogen production methods would result in decreased CO emissions relative to conventional vehicles.

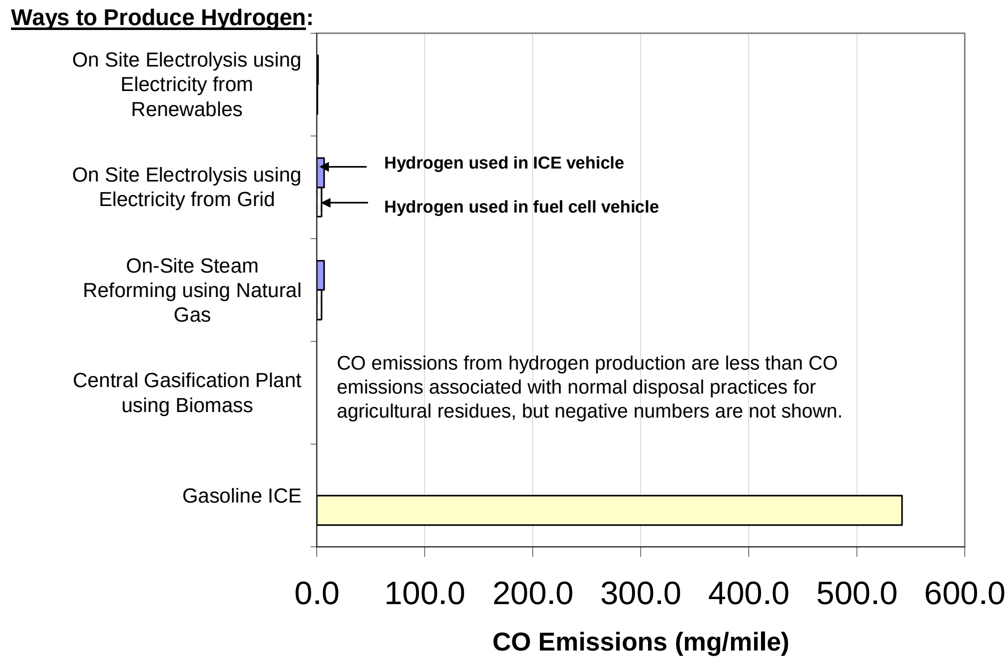

Figure 4-10 – Source-to-Wheels CO Emissions

Energy Efficiency

Improvements in energy efficiency and reduced use of energy resources generally result in concomitant environmental benefits.[48] Thus, they are important to take into consideration when determining the best hydrogen production pathways. A source-to-wheels (STW) energy analysis can indicate levels of energy efficiency for different pathways. As Figure depicts, STW energy consumption and use of different primary fuels vary significantly from pathway to pathway. For example, natural gas production of hydrogen used in FCVs uses two-thirds of the energy required for gasoline vehicles, but hydrogen produced from grid electrolysis and used in an H2ICEV uses more than twice as much energy. Also, some renewable energy pathways, such as H2ICEVs using hydrogen from solar electrolysis, are not as energy efficient as gasoline in comparable ICE vehicles, yet they improve GHG and criteria pollutant emissions, energy diversity, and petroleum dependence. In fact, all four hydrogen pathways shown in Figure 4.11 use less petroleum than gasoline but not always less energy.

[48] Many examples exist, and benefits can be inter-related. For example, combusting less gasoline through conservation or improved efficiency can result in less criteria and GHG emissions, while also requiring less extraction of crude oil, which can avoid a variety of negative impacts on water quality, land, wildlife, etc.

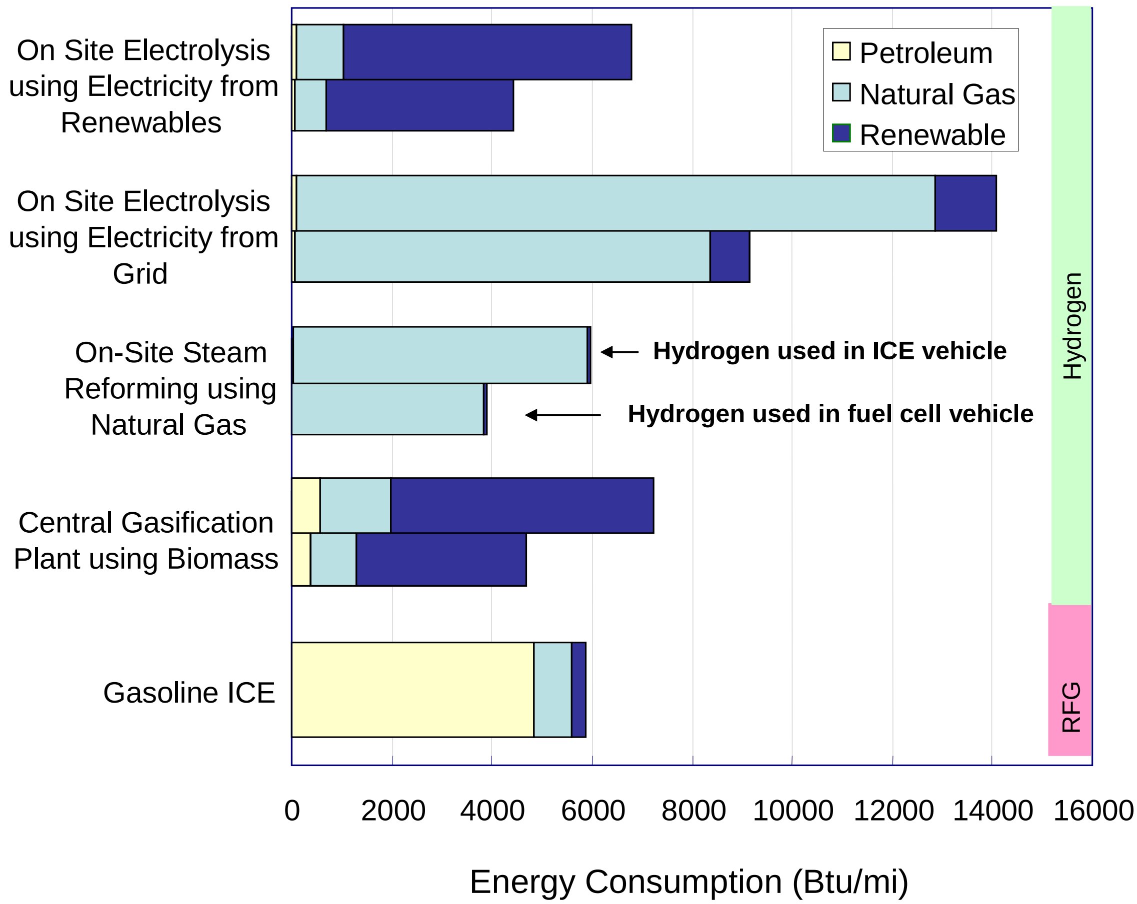

Figure 4-11 – Source-to-Wheels Energy Consumption

As a result, although the various hydrogen and gasoline pathways result in a range of energy consumption levels, the figure shows that energy efficiency does not always equate with petroleum reduction or lower emissions. For example, as shown, it takes nearly as much energy to drive a fuel cell vehicle with hydrogen generated from renewable electrolysis as it does to drive the same car with hydrogen generated from natural gas, yet emissions for the renewable electrolysis pathway are nearly zero. Thus energy efficiency is only one of several important factors in choosing fuels, pathways, and vehicles.

Renewable Resource Options

As described in this report, there are many different ways to produce hydrogen from renewable energy. Even among renewable energy electricity pathways, there are a variety of options, which result in varying levels of GHGs, criteria pollutants, and energy use. To better understand tradeoffs for different renewable energy electricity options, the Societal Benefit Team compared and rated various types of renewable power.

The results of the analysis showed that for the purpose of producing hydrogen, it is important to require that any "renewable hydrogen" be produced from new renewables rather than existing renewables (see Glossary for definitions). New renewables guarantee that power is produced from renewable resources and that the power is "excess," meaning it is not used to meet any other renewable obligations. Production of hydrogen from existing renewables could actually increase emissions by displacing existing electricity demand and thereby increasing natural gas electricity generation. As a result, this option was not considered to be desirable for implementation under the CA H2 Net.

Another option considered for renewable power was the purchase of out-of-state renewable generation that does not actually supply energy to California but supports renewables elsewhere, commonly known as "green tags," or renewable attribute-only purchases. However, the purchase of energy from a renewable resource that does not actually supply energy to the state results in additional in-state natural gas generation. As a result, the environmental impacts in terms of criteria pollutant emissions would be equivalent to natural gas generation. The GHG emissions in this arrangement would depend on the type of fuel being offset by the renewables. See the Societal Benefits report for further discussion of green tags.

The Societal Benefit Team's analysis of environmental benefits due to use of renewables to offset natural gas in the electricity grid versus those applied to transportation offsetting petroleum showed that transportation offsets are better for reducing NO_x and petroleum dependency though not necessarily for reducing the GHG CO_2. The Societal Benefits report provides further details on this analysis

The societal benefit analysis also assumed use of a variety of renewable sources of energy that have significant differences in operating and manufacturing emissions, specifically NO_x emissions associated with generating electricity from biomass and waste resources, as well as CO_2 emissions associated with natural gas co-firing of thermal facilities. The net emissions analysis indicated that some resources are lower emitting than others. However, auxiliary benefits of various renewable resources could offset the emissions. These could include benefits in reliability and manageability of the grid, diurnal and seasonal storage opportunities, or architectural or operational benefits for facilities.

Environmental Goals

As supported by the figures in this section, in the absence of specific goals for reducing emissions (GHGs and criteria pollutants) and using renewable resources to produce hydrogen, the Societal Benefits Team found that the CA H2 Net may not meet the environmental and renewable resource directives established in EO S-7-04. Further, without such goals, GHG and PM emissions could increase relative to gasoline and diesel vehicles.

To ensure GHG emission reductions in the 2010 timeframe and to set the stage for a long-term goal of near-zero GHG emissions from the transportation sector, the Societal Benefits Team approved GHG goals and recommendations. In addition, because there are production methods and uses of hydrogen that can increase criteria emissions relative to conventional vehicles, the Societal Benefits Team also agreed that it is important to have criteria and air toxic pollutant goals and recommendations.

The Societal Benefits Team reviewed and analyzed various policy options for incentives for pathways and vehicles with the greatest societal benefits. These recommendations are included in the overall recommendations summarized in Section 6.

Inclusivity of Other Beneficial Fuels and Technologies

One finding of the Societal Benefits Team, which has been reinforced by the Advisory Panel, is that California's move towards hydrogen must be part of a broader energy and environmental strategy. This strategy must include a portfolio of other vehicle technologies and fuels, in addition to hydrogen vehicles and infrastructure. The CA H2 Net is not meant to exclude or oppose government support (policy, funding, etc.) for other clean fuels and technologies, especially considering the important benefits of bridging technologies. The Societal Benefits team therefore found that the CA H2 Net must be inclusive of other fuels and technologies that are helping to meet California's environmental and energy objectives: non-hydrogen vehicles and fuels have been, and will continue to be, important and vital aspects of the State's broader environmental and energy strategy.

4.3.3 Economy Team

4.3.3.1 Mission

The Economy Team's mission was to assess the estimated costs of implementing the CA H2 Net and options for attracting the investment capital needed to finance the network. The Team's main effort involved modeling the estimated infrastructure-related costs for the CA H2 Net. A model was developed specifically with the purpose to predict realistic near-term hydrogen station costs, and identify and quantify important factors that affect station cost. The Team also evaluated operating costs and revenues for different types of stations.

4.3.3.2 Summary of Findings

Summary of Phase 1 Cost Estimates

Today 39 stations are in operation or are planned for construction in the near term. The Advisory Panel recommendation for station deployment in Phase 1 is 50 to 100 stations. To assure that Phase 1 meets the lower bound target of 50 stations, 11 new stations are needed. At an estimated average cost of $1 million each, these 11 stations will cost $11 million to build. To reach Phase 1's upper bound target of 100 stations a further $54 million total funding would be needed, as shown in Table 4-2. This estimate includes several energy stations with costs greater than the average $1 million.

Table 4-2. Estimated Infrastructure Investment to Implement Phase 1 of the CA H2 Net

Phase 1 Hydrogen Infrastructure Costs	Total Estimated Costs(millions)
11 Additional Stations (note 1)	$11.0
Next 50 Stations (note 2)	$54.0
Total Estimated Cost of Phase 1 Hydrogen Infrastructure (see note 3)	$65.0

Table Notes:

1. An estimated 39 hydrogen stations are built or being planned through existing programs. 11 additional stations are needed to achieve the lower-end Phase 1 goal of 50 stations.
2. 50 additional stations (including some energy stations) will be needed to achieve the upper-end Phase 1 goal of 100 stations.
3. These costs are based on findings from the Economy Team Report and extrapolated for 50 and 100 station scenarios

The Economy Topic Team's hydrogen cost model predicted station infrastructure costs, as well as operating costs and revenues for the types of stations shown in Table 4-3. The infrastructure costs modeled by the Economy Team were based on equipment and siting requirements for each type of station. The Economy Topic Team Report and its appendices provide detailed infrastructure cost breakdowns for each type of station, as well as assumptions and calculation methodologies.

One finding in the Economy Topic Team Report was that private industry cannot justify investing this magnitude of private capital "based on expected returns over the near term . . . given the immaturity of the market, projections of product availability, and the time needed to develop (significant) throughput at hydrogen fueling stations."[49] Without government cost sharing through the CA H2 Net, Phase 1 is unlikely to be implemented.

Operating Costs and Revenues

The costs of the stations, including operating costs, are sensitive to several factors. Station location, fuel source for hydrogen, and capacity utilization are examples of these factors. Revenues depend on hydrogen prices and capacity utilization. With an assumed retail price of $3/kg for hydrogen, the net operating costs (operating costs minus revenues) are $3.6 million to $7.2 million annually for 50 to 100 stations. These values are based on the Economy Team's reported average net operating costs for the first 50 stations. It is important to note that the values represent costs for the total number of stations in the CA H2 Net rather than only stations whose infrastructure costs are supported by the State of California. See the Economy Topic Team Report for detailed descriptions and sensitivity analyses of input assumptions for operating costs and revenues.

Station Mix Used to Estimate Costs for Phase 1

The station mix shown in Table 4-3 was developed to represent the first 50 stations in the CA H2 Net based on a number of assumptions described in the Economy Topic Team

[49] See Economy Team report.

Report. This station mix was used to determine the estimated infrastructure costs for the State of California during the first phase of the CA H2 Net, in which 50 to 100 stations should be built. Because there are already 39 existing stations or stations with planned financial support through other programs, the mix was used to develop the State's infrastructure costs for the 11 to 61 remaining stations in the first phase.

Table 4-3. Station Type, Rated Capacity, and Station Mix[50]

Station Type	Capacity (kg/day)	Station Mix	Number of Stations
1 Steam methane reformer	100	12%	6
2. Electrolyzer, grid electricity	30	6%	3
3. Electrolyzer, some photovoltaic electricity	30	18%	9
4. Electrolyzer, grid electricity	100	10%	5
5. Mobile refueler	10	20%	10
6. Delivered liquid hydrogen	1,000	8%	4
7. PEM/Reformer 8. High-temperature fuel cell energy station	90-100	18%	9
9. Pipeline hydrogen station	100	8%	4
Total			50

Note: The model also included a 1000 kg/day steam methane reformer but this station type was not represented in the station mix for the first 50 stations

Preliminary Outlook for Costs of Phases 2 and 3

The costs to implement Phases 2 and 3 will depend on the success achieved during Phase 1. Assuming the upper limit of 100 stations is achieved for Phase 1, an additional 150 stations should be targeted for completion by the end of Phase 2. The cost of adding these additional 150 hydrogen fueling stations was estimated at approximately $76 million, reflecting a lower per station cost as volumes increase and fueling technologies mature. Whether or not California should share these costs would depend on how industry views the risks and returns associated with this level of investment.

Similarly, it is not clear that vehicle incentives will be needed in these later phases. Technical successes in on-board hydrogen storage, fuel cell costs, and fuel cell durability could obviate the need for incentives.

[50] The Station Mix was jointly developed by the Societal Benefits and Economy Teams. The Mix meets all of the environmental goals recommended by the Societal Benefits Team.

4.3.3.3 Additional Findings and Conclusions from the Economy Team

The Economy Team also made the following findings:

- Hydrogen fuel costs measured in dollars per kilogram will be higher at small stations that are burdened with high installation costs and low utilization of station infrastructure. However, small stations (less than 100 kg/day) represent a low risk, low investment approach to achieve the state-wide build out of hydrogen infrastructure contemplated by the executive order. Additionally, such stations would support early fleet users by providing exceptional flexibility. Small size, low capacity factor infrastructure is consistent with expected fueling requirements for early hydrogen infrastructure deployment.

- Lower hydrogen fuel costs will be achieved with hydrogen stations that have economies of scale in fuel delivery, likely requiring fleet applications for early station introduction.

    - Favorable electricity prices are available in some jurisdictions for large users (>500 kW) who have the flexibility to take advantage of time-of-use rates and interruptible service. Note: Further work will be needed to determine the practical implications (if any) of this finding to the CA H2 Net and station end users.
    - Fixed operating costs can be amortized over more delivered fuel for larger fuel stations.
    - Capital and installation costs decrease significantly per unit of output with increasing hydrogen energy station size.

- High-temperature fuel cell energy stations and pipeline-based stations deserve special consideration, since they result in the lowest-cost hydrogen. While applications for these specialty stations are limited to locations with an sizeable hydrogen demand, this demand allows for much higher utilization of the energy station asset. In the case of high-temperature fuel cell energy stations, these stations would be sited at either commercial and/or industrial locations with a hydrogen demand currently addressed with delivered bottled hydrogen. The hydrogen generated by the energy station would be used primarily to displace bottled hydrogen used at the facility, with a dispensing station available to fuel vehicles when and if needed. Since the costs of producing hydrogen using this technology is lower than the bottled hydrogen costs it displaces, this specialty station has the potential of being self-funded from the revenues produced by the sale of electricity, hydrogen and heat to the host facility. Although the high-temperature fuel cell option looks promising and involves the integration of two already commercially available technologies (the fuel cell itself and a pressure swing adsorption hydrogen purification system), this type of unit has not yet been built and tested as an integrated system. Thus, these are expected costs and not field-tested costs.

- Achieving the goals set by the U.S. DOE and Governor Schwarzenegger's Executive Order for a sustainable hydrogen economy based on renewable energy will require a combination of efforts from industry and government, focused on technology and policy.

- Policy initiatives that support renewable energy and hydrogen generation include:
    - Extension of time-of-use electricity pricing to smaller industrial electricity users.
    - Extension and harmonization of interruptible service rates across all California utilities and to smaller meter users (<500 kW) involved in the hydrogen highway.
    - Power purchase agreements between renewable energy providers and hydrogen generators to provide appropriately priced renewable power and incentive for new renewable power capacity in connection with the hydrogen highway.
- Technology developments underway in support of renewable energy and the hydrogen highway include:
    - Decreasing cost of renewable power generating equipment by major wind turbine and solar PV manufacturers
- Declining costs for electrolyzer equipment capital cost, resulting from:
    - Product design simplification
    - Volume manufacturing
    - Implementation of lower cost materials
    - Improved efficiency of electrolyzer / compression systems from current 60 kWh/kg to 50 kWh/kg with identified technology improvements.
    - Decreased installation costs through repeat installations and learning by regulators and infrastructure providers.
- With the combination of appropriate policy initiatives, technology advancements and eventual scale up in product size and manufacturing volume, the goal of a hydrogen economy that is sustainable and economical is readily achievable by 2020.

4.3.3.4 Potential Funding Mechanisms

The Economy Team investigated a wide variety of potential mechanisms to fund implementation of the CA H2 Net, although no specific cost numbers were established at the time of this assessment. Potential funding mechanisms that were assessed included market-based concepts, taxes, subsidies, and mandates. The team discussed a wide array of ideas, but did not make any formal recommendations. The various funding options considered by the Economy Team involved the following categories:

- ***Market-Based Mechanisms*** aimed at influencing the financial attractiveness of investment in the CA H2 Net;

- ***Mandates*** that actively affect behaviors of various private or public actors;

- ***Cross Subsidies*** that transfer some of the benefit of current subsidy programs from existing recipients to new recipients—namely, the participating service providers in the CA H2 Net (for example, transfer of a portion of existing gasoline tax receipts to the program);

- ***New Subsidies*** that involve new taxes or other new revenue sources to enable the program;

- ***Non-Profit Organizations*** with public-service or philanthropic missions that embrace environmental / energy sustainability or economic development goals;

- ***Reinforcing Mechanisms,*** such as awards and incentives which, while not sufficient to fund the fueling infrastructure, may contribute to the broader goal of accelerating development of the hydrogen economy.

Among the major ideas discussed for potential implementation were the following:

- Revenue Bonding and/or General Obligation Bonds backed by various types of taxes or fees (e.g., involving fuel purchase and vehicle registration).

- Requirements for existing transportation fuel suppliers to provide relatively small volumes of hydrogen fuel by 2010.

- Encourage "dual use" energy applications such that energy stations, established to generate electricity and usable heat for local customers and/or valuable "on-peak" electric power, can co-generate hydrogen and provide facilities for dispensing hydrogen for refueling vehicles.

- Provide tax credits for companies making qualified investments in the CA H2 Net.

- Require that a growing proportion of new state-operated vehicles and, later, private vehicle fleets (including rental car fleets), be fueled by alternative fuels, including hydrogen.

Additional ideas and concepts were provided by members of the Advisory Panel, and others. For example, suggestions were made that early vehicles deployed and hydrogen fuel sold under the CA H2 Net should be exempt from various types of taxes. A public-private partnership developed to implement the CA H2 Net could play a key role in determining the best policies to fund the program's various phases.

4.3.4 Implementation Team

4.3.4.1 Mission

The Implementation Team's mission was to facilitate the timely, safe, and effective deployment of a hydrogen energy infrastructure for transportation and stationary power applications in California by 2010. The most critical part of this mission was to identify actions needed to support the development and uniform implementation of regulations, codes, and standards for hydrogen stations. The Implementation Team's full scope included a wide variety of logistics and issues in the following general categories:

- Codes & standards
- State, federal and local regulations
- Station permitting requirements
- Insurance requirements
- First responder community

4.3.4.2 Summary of Findings

The Implementation Team found that there were elements of hydrogen use that are not effectively covered by currently adopted codes & standards or insurance practices for conventional fuels. The primary target for discussion was vehicle refueling stations available for public use. This included fuel delivery to the site, on-site fuel storage, and fuel dispensing to vehicles. In addition, consideration was given to stations that will include on-site hydrogen production, as well as "energy station" concepts where the station can also generate electricity for on-site or grid-connected uses. Onboard vehicle standards relating to hydrogen were not in the scope of work for this team, as they are being developed in other forums. Centralized or off-site hydrogen production and its transport to fueling stations are already supported by existing codes and standards.[51]

In developing its recommendations, the Team sought to accommodate the needs of public and private stakeholders, permitting and regulatory officials, codes and standards development organizations, industry, and end users of hydrogen-fueled vehicles and products. The Team found three general areas where changes are needed:

1. Streamlining the process of implementing and enforcing codes & standards: identification and roles of authorities having jurisdiction (AHJ)

2. Adjustments to current California codes & regulations for hydrogen designed for industrial use in specific applications

3. Obtaining insurance coverage

The Implementation Team developed an extensive list of recommendations to bring about these changes. These recommendations are included in Section 6 within the full context of implementation for the CA H2 Net.

4.3.5 Public Education Team

4.3.5.1 Mission

The Public Education Team's mission was to prepare a state-supported marketing, communications and public education plan to maximize the visibility of the CA H2 Net in the 2010 timeframe, by fostering understanding, acceptance and support of hydrogen. Targeted audiences included stakeholders, consumers and the general public.

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[51] A member of the Advisory Panel noted that despite perceived codes coverage for central production and transport, smaller, more-versatile hydrogen delivery units may still need additional attention regarding codes & standards.

An important aspect of the Public Education Team's work was identifying opportunities and challenges involved in educating different audiences. Subteams were formed to determine the education requirements for several audience categories, including technology and industry enablers, government, policy makers and influencers, consumers and customers, and the education community. These efforts resulted in the development of recommendations for the types of core messages and marketing necessary for the CA H2 Net.

4.3.5.2 Summary of Findings

The Public Education team found that introducing new fuels and technologies into the market place requires carefully coordinated efforts involving education, communications, and marketing. The following is a core message identified by the Public Education Team that cuts across all audiences and should be clearly communicated to the public:

California is becoming a world leader in adopting a hydrogen economy, to address energy, environmental and economic issues that are critically important to the people of the State. The CA H2 Net will:

- Improve California's environment by reducing emissions that may have an impact on air quality and health
- Make California's energy future more secure, stable and sustainable
- Improve California's economy and create jobs

The Public Education Team's main findings are organized around four distinct audience groups. The core messages tailored for each group are summarized below. The major outputs of the Team were specific action items and recommendations that have been incorporated into Section 6. They can also be found in the Public Education Team Report.

Technology and Industry Enablers

The Team found that the CA H2 Net organization must communicate with companies and industry associations, labor organizations, research institutions and others who will have an important role in facilitating technology advancements and commercial installations involving hydrogen. It must be communicated that hydrogen technologies offer business opportunities, and California is a prime business location. They also need to be motivated – as a way of furthering their business and professional interests – to help communicate with their peers, their customers and their communities.

Government, Policy Makers and Policy Influencers

Moving hydrogen technologies forward and spurring the installation of hydrogen infrastructure requires state and local policy makers to provide key policy drivers and remove unnecessary barriers. This audience needs to be motivated by understanding that their actions, if sustained and stable, can make California a world leader in hydrogen development and deployment, and that doing so will reap rewards for the state. These rewards include job growth, a strengthening of the state's economy; environmental improvement, and a more sustainable and secure energy system for California. At the same time, this key audience needs to be educated to understand more about hydrogen, and especially that technologies and process to produce, deliver and use hydrogen will be safe.

Consumers, Customers and News Media

To motivate this group, which includes the general public, to accept policies in support of hydrogen, it needs to be clearly conveyed that hydrogen technologies are consistent with important state policies to provide stable, sustainable energy for California.

On a consumer level, the general public needs to become familiar and comfortable with hydrogen, understanding that it is as safe as or safer than other fuels, and understanding that hydrogen products such as fuel cell vehicles will deliver the performance and utility they expect. The public's consumer expectations must be tempered, however, to not expect too much too soon, understanding, for example, that hydrogen vehicles will be available first to fleet operators, and more gradually to the general motoring public (individual consumers).

At the local level, early and concentrated communication delivering the messages summarized above is essential with community stakeholders in locations where hydrogen fueling stations and demonstration projects are being installed. Their comfort, and even pride, in having a hydrogen program in their neighborhood needs to be fostered to avoid possible opposition stemming from lack of knowledge about hydrogen.

Education Community

A sustained program is needed to work with all levels of California's education system to help teachers and administrators fulfill the roles they can play in building the state's hydrogen economy and in realizing the opportunities available to their institutions. Basic concepts relating to energy, hydrogen, and fuel cells need to be incorporated into curriculum guidelines at all educational levels within the state.

K-12 schools and teachers have a key role in preparing the future professionals and consumers who will make the transition to a hydrogen economy. Educators at this level need and are eager to receive hydrogen training, curriculum guidance and classroom materials. In addition, California's educational content standards must be adapted to incorporate hydrogen education at the K-12 level.

Community colleges can be central to workforce development efforts by incorporating hydrogen and sustainable technology in the Economic and Workforce Development Program, creation of new degrees and certificate programs, and through career training programs for emergency responders, technicians and others who will need hydrogen training.

California's colleges, universities and research institutions can expand their international leadership in energy, hydrogen and fuel cell research, expand their role in training world class engineers, scientists, business leaders and policymakers in these fields, and by their very presence and reputation can help attract hydrogen business to the state.

5.0 Issues and Alternative Opinions

This section provides an overview of some issues and alternative opinions that were raised during the preparation of the Blueprint Plan. Each is followed by a brief response about how (or if) agreement on how to resolve the issue was reached. In some cases, it is noted that further action may be necessary in subsequent Blueprint Plans for the CA H2 Net.

A clear consensus emerged from the wide array of participants that California should continue and strengthen its leadership role in transitioning towards widespread, sustainable use of hydrogen. Nonetheless, some issues and alternative opinions were raised during the preparation of the Plan. Highlights of these issues are provided below. Responses, compiled by the EO team, are provided based on information that emerged from the process to prepare the Blueprint Plan.

5.1 Long-Term Planning and Transition to Subsequent Phases

Issue/Opinion: The Blueprint Plan for the CA H2 Net needs greater details and additional mechanisms for success beyond 2010. The results so far are optimized for short-term investigation and success without considering hydrogen pathways that can best result in long-term success. The set up of a hydrogen infrastructure is a cost-intensive process, even in the initial phases, which has to be carefully and strategically planned by industry as well as public institutions. The building up of a hydrogen infrastructure has to be optimized for costs and emission reductions through a long-term plan, to be realized as effectively as possible. The Blueprint needs to be more specific about how California will transition from Phase 1 into Phases 2 and 3. What are the decision points? On what criteria will they be based?

Response/Resolution: The objective of the first Blueprint under the CA H2 Net was to create a preliminary action plan for deploying hydrogen fueling stations in California by 2010. It serves as the foundation for long term commercial success. This first step is fully discussed in the Blueprint Plan report. The Blueprint includes a step-by-step process that will manage early risks based on many factors. It is recognized that a longer-term plan is needed to develop a truly sustainable program but that cannot happen without first laying a foundation. Using this initial action plan and taking into account technological progress evaluated at biennial reviews, it is envisioned that more detailed plans will emerge over the next few years that extend out into the next decade, and possibly beyond. At this time, more work and information coming from on-the-ground projects are needed before specific decision points can be identified.

5.2 Technological Readiness and Hurdles

Issue/Opinion: The Blueprint does not fully acknowledge the technological hurdles that must be resolved before hydrogen vehicles and fueling stations can be commercially deployed. Significant barriers with fuel cell systems exist, especially regarding cost, durability and consumer acceptance issues. Other issues require additional research and development, such as on-board hydrogen storage. Technological and commercial readiness of hydrogen vehicles will mostly dictate the pace that California can successfully proceed to a sustainable hydrogen economy. Building fueling stations should not "get ahead" of the end-use technologies.

Response/Resolution: This issue was raised early in the Blueprint process. The Blueprint now includes greater detail and discussion about technological issues and limitations, with appropriate checks and balances. The Advisory Panel, which includes experts from automotive and energy companies, reached agreement that Phase 1 of the CA H2 Net is achievable in the 2010 timeframe. All parties involved generally concurred with the 2004 National Academies of Science report which noted that, while technical issues exist and must be overcome for this vision to become reality, there are no technical showstoppers. The Advisory Panel agreed that California can work with energy companies to build a fueling infrastructure to match vehicle rollout, and the associated costs are manageable. They agreed that this should proceed as a world-class, phase-by-phase effort to deploy hydrogen fueling stations and vehicles. The specific purpose of the biennial review process outlined in the Action Plan should be to assess technological progress and commercial readiness before proceeding towards further investments and subsequent phases.

Issue / Opinion: There is insufficient rationale for supporting hydrogen internal combustion engine (ICE) vehicles under the CA H2 Net. The costs might not justify the environmental benefits, especially for what may be an interim technology. Support for hydrogen ICE vehicles might "retard" development of hydrogen fuel cell vehicles.

Response / Resolution: There are numerous reasons to support and incentivize hydrogen ICE vehicles as part of the CA H2 Net. Several major automobile manufacturers have made very significant investments in hydrogen ICE technologies for vehicles, and two (Ford and BMW) have publicly indicated that they plan to commercialize such vehicles. In addition, certain small-volume manufacturers and vehicle conversion companies plan to commercialize hydrogen ICE vehicles. These plans are indicative of real potential for commercialization. Additionally, H2ICEs can provide immediate emissions and petroleum-reduction benefits versus gasoline vehicles.

Demand for hydrogen fuel at CA H2 Net fueling stations will be increased through deployments of ICE vehicles. Many CA H2 Net participants (including auto manufacturers working on fuel cell vehicles) have noted that the costs of fuel cell systems must be significantly reduced before they will be viable in the transportation sector. Support for Hydrogen ICE technology under the CA H2 Net can be viewed as part of a "bridge" strategy, given this present economic hurdle for fuel cell vehicles.

One of the biggest technological hurdles facing any type of hydrogen vehicle is the need to develop affordable on-board hydrogen storage technologies with acceptable volumetric and gravimetric energy density to achieve satisfactory driving range. This will best be accomplished through pooled demand for on-board hydrogen storage systems from automakers developing either type of hydrogen vehicle (ICE or fuel cell). Finally, the U.S. DOE's hydrogen program envisions an important role for H2ICE vehicles on the pathway to a hydrogen fuel cell transportation system.

Issue / Opinion: Some of the analyses that were done to establish hydrogen costs and benefits were based on technology that is likely to change. For example, the working pressure for compressed gaseous hydrogen systems was assumed to be 5,000 psi. Higher pressure systems (10,000 psi) may be needed to provide acceptable driving range for vehicles that use compressed hydrogen. Such systems will entail higher costs for stronger materials, and increased energy demands for higher gas compression. These types of impacts associated with changing technology need to be assessed.

Response / Resolution: This raises an important point: technology to generate, store and use hydrogen is likely to undergo significant change, even within the relatively short timeframe of Phase 1 for the CA H2 Net. Again, a key role of the biennial review process should be to assess the commercial implications of these technological improvements. Necessarily, the first Blueprint analyzed hydrogen technologies as a snapshot in time. While it is true that changes may make these analyses obsolete or incomplete, in general technological change is more likely to reduce costs and improve benefits for hydrogen-related technologies. For example, one major auto manufacturer recently announced they have achieved and exceeded the U.S. DOE's cost-per-kilowatt goal. A manufacturer of fuel cells recently announced it has been able to reduce the amount of platinum needed in the fuel cell stack, representing the potential for significant cost savings. And a recent string of manufacturers announced that they have overcome the hurdle of operating fuel cells in sub-freezing temperatures. Thus, the analyses reflected in this Blueprint may very well reflect worst-case scenarios for costs and benefits. In addition, optimal vehicle or equipment applications for hydrogen H2ICE and fuel cell technologies may evolve over time, meaning that in some cases it may not be appropriate to evaluate current costs and benefits, including energy consumption.

5.3 Alternative Approaches for Societal Benefits

Issue / Opinion: The best way to displace petroleum in the transportation sector is through expanded use of gasoline and diesel hybrid-electric vehicles. California should constantly assess progress of this type of emerging technology, or any others that could provide the same potential benefits as the CA H2 Net.

Response / Resolution: The CA H2 Net is part of our state's broader, long-term strategy to reduce petroleum dependence and address environmental problems. Although improvements to conventional gasoline vehicles are the near-term component of the overall strategy, California cannot achieve its petroleum displacement and environmental protection goals solely through such efforts. This is because the number of vehicle miles traveled by California's motorists is growing at a rate which will overwhelm projected improvements.

It is valid to note that California should constantly assess technology under the CA H2 Net. This should be accomplished through the biennial review process described in this Blueprint. Close coordination should be conducted with other efforts to assess technology and commercial readiness. Assessments should focus on performance goals, i.e. effectiveness at meeting environmental and petroleum displacement goals with a long-term vision.

Issue / Opinion: The CA H2 Net is "receiving a disproportionate amount of attention" and "crowding out" alternatives that may be more practical, energy efficient, and/or achievable in the near term.

Response / Resolution: The Blueprint Plan addresses this concern in the "Inclusivity Policy" (See Section 4.3.2.2). This policy recognizes that the development of complimentary technologies is essential to development of a hydrogen economy and states that California should continue to evaluate and support investments made in other alternative fuels and technologies if they offer clear and compelling societal benefits. It also notes that these technologies are necessary to achieve immediate petroleum and emissions reductions. Examples of such fuels and technologies include, but are not limited to, battery electric vehicles, plug-in hybrids, and natural gas vehicles. Emphasis should be put on those fuels and technologies that involve renewable energy pathways. Details can be found in the Societal Benefits Topic Team report.

Issue / Opinion: Direct use of electricity to recharge battery electric vehicles (BEVs) or "plug-in hybrids" will provide higher efficiency and greater societal benefits than using a hydrogen-based strategy for vehicle propulsion. BEVs and plug-in hybrids will need less energy than hydrogen vehicles (including fuel cell vehicles) to support an equal number of vehicle miles. Improvements in long-life storage batteries enable BEVs to achieve driving ranges of 200 to 300 miles. Applications requiring longer ranges and quick refueling can take advantage of emerging plug-in hybrid technologies.

Response / Resolution: These arguments have technical validity, but may not consider the larger picture. Many major manufacturers have discontinued their BEV programs and none have publicly expressed plans to commercialize BEVs or plug-in hybrids. This, however, does not mean these technologies do not exist or will not advance in the future. The Inclusivity Policy was included for such developments.

The recommendations of the Blueprint Plan are predicated on a *broad spectrum* of attributes, and a long-term vision for California. Many potential benefits and factors have been taken into account for success. These include stakeholder support, the stated commercialization plans of vehicle manufacturers, existing partnerships that can be leveraged, synergy with bridging technologies for hydrogen (including electric drive, which will be advanced through the CA H2 Net), and potential for broad acceptance by the public. Perhaps most important is the bigger energy picture for California. As energy use in the transportation sector is diversified, it is also necessary to consider what may be the most efficient and cost effective use of energy resources for power generation, industry, commercial, and residential uses. Based on the compelling combination of attributes described in this Blueprint, moving forward with a plan that specifically focuses on hydrogen fuel appears to be the right course of action.

5.4 Hydrogen Production Pathways

Issue / Opinion: Even the most benign hydrogen production pathways will not necessarily result in net improvements in greenhouse gas (GHG) emissions. For example, making hydrogen with electricity from a renewable energy source (e.g., wind or solar power) will result in more CO_2 (a GHG), because combustion-based powerplants on the electricity grid will be used to "pick up the load that the renewables would otherwise have provided energy for." Generation of hydrogen with electricity should be evaluated using assumptions for the marginal electricity generation in California. Based on calculations for hydrogen generated in a typical grid-powered electrolyzer and used to fuel a state-of-the-art prototype fuel cell vehicle, the grams per mile CO_2 equivalency for the vehicle will be worse than a current gasoline vehicle that achieves only moderate fuel economy.

Response / Resolution: The CA H2 Net has specifically set a goal of using new renewables (see glossary) to provide power for electrolysis to ensure that fossil fuel emissions are not simply shifted among end-use applications. Section 3 discusses these electricity production options. California currently uses petroleum (and ethanol, as an oxygenate in gasoline) for transportation while the rest of the state's energy needs are divided among various energy resources. As the CA H2 Net moves forward and California diversifies its options for transportation energy, it will be important to assess the most effective allocation of available types of energy resources to meet transportation and electricity generation demands. Source-to-wheel emissions should play a role in the analysis, as should costs, convenience, technology readiness, resource availability, and other metrics.

Finally, the State's CO_2 mitigation efforts must be balanced with its petroleum-reduction efforts. Both are components of eliminating the security, environmental, and economic threats to California from its transportation sector's heavy dependence on petroleum. The CA H2 Net is an effort to incorporate those CO_2 and petroleum-reduction efforts with each other and similar initiatives.

Issue / Opinion: The Blueprint needs greater discussion about reforming renewable liquids such as ethanol. Steam reforming of ethanol is the least costly renewable source of hydrogen. The Blueprint Plan discussion regarding this production pathway was mostly limited to providing hydrogen to rural or remote locations. Ethanol can be stored in existing underground gasoline storage tanks, and on-site reforming could occur in California at many if not most of these existing facilities. California should consider a refueling program to support the approximately 300,000 flexible fuel vehicles in the state that are capable of running on E-85 (a blend of 85% ethanol and 15% gasoline). The onsite tanks of pure ethanol (before blending) could serve as feedstock for hydrogen reforming, resulting in dual-purpose fueling stations. This would be a very cost-effective bridging strategy to renewable hydrogen.

Response / Resolution: This type of renewable hydrogen pathway is not precluded under the CA H2 Net, and the potential for further work exists. Currently, California uses large volumes of ethanol as an oxygenate in gasoline. This meets federal requirements and helps displace petroleum fuel. The ethanol industry has made some preliminary overtures towards providing an E-85 fueling infrastructure in California for flexible fuel vehicles. Further infrastructure investments should involve business decisions as well as regulatory considerations, which are not likely to be driven by the potential to make hydrogen. The CA H2 Net should continually assess the best pathways for hydrogen production within the full context of California's overall energy needs and strategies.

5.5 The Role of Academia

Issue / Opinion: The CA H2 Net action plan should recommend new programs to ensure that California's research and educational institutions are key to development of new high-technology clean energy industries, creating jobs and economic growth. The

Blueprint Plan should have stronger emphasis on research and education as key factors in moving toward a hydrogen economy, given that technological innovation is required to enable a sustainable energy future. New university-industry partnerships should be created along with California "research centers of excellence" in the areas of hydrogen storage, fuel cell technology, and renewable hydrogen infrastructure.

Response / Resolution: The Blueprint and the accompanying report from the Public Education Topic Team contain some details addressing this type of role for California's institutions of higher learning. If needed, additional efforts can be scoped out as part of the biennial review process.

6.0 Conclusions and Recommendations

The following set of recommendations will help enable the successful commercialization of hydrogen in California. These recommendations lay out a broad sketch of the "what, how, where and who" of the Blueprint plan. Recommendations range from overarching philosophy, deployment guidelines, specific criteria, and required actions. For more detailed information regarding technical elements and findings that support these recommendations, as well as additional recommendations, please refer to the individual Topic Team reports.

6.1 Defining the Hydrogen Highway Network

The California Hydrogen Highway Network is a State initiative to promote the use of hydrogen as a means of diversifying sources of transportation energy, while ensuring environmental and economic benefits. Implemented in phases, the Blueprint Plan outlines a path to 250 hydrogen stations and 20,000 hydrogen vehicles, which will help set the stage for full scale hydrogen commercialization. The broad mix of stakeholders involved in the CA H2 Net process have agreed that by 2010 a first phase of the CA H2 Net is achievable, and they are expected to build hydrogen stations as vehicles are deployed. The Advisory Panel, based on the findings of the Topic Teams, recommends the following critical path for the CA H2 Net:

- Implement the CA H2 Net program in phases, beginning as soon as possible with Phase 1. The transition to hydrogen fuel in California will require a long-term commitment and the best efforts of government, industry and consumers alike. The CA H2 Net is a long-term effort that should begin now.
- Thorough biennial reviews should be undertaken, making periodic assessments of technological maturity and commercial readiness for vehicles and other hydrogen-fueled products. Results of the biennial reviews should evaluate progress on implementation of the Blueprint Plan and inform the path forward to subsequent phases of implementation. Results of the biennial reviews should also help define timeframes for completion of Phases 2 and 3.
- Phase 1: Deploy 50-100 hydrogen stations in California by 2010, including existing stations and those already planned through other programs. Deploy 2,000 hydrogen-fueled light-duty vehicles, 10 heavy-duty vehicles, and 5 stationary or off-road hydrogen applications in California by 2010.
- Phase 2: Assuming sufficient progress with vehicle deployments and other milestones in Phase 1, as judged by the results of biennial reviews, target a total network of 250 fueling stations by the end of Phase 2. In tandem with the 250 stations, deploy 10,000 hydrogen-fueled light-duty vehicles, 100 heavy-duty vehicles, and 60 stationary or off-road hydrogen applications.
- Phase 3: Deploy 20,000 hydrogen-fueled light-duty vehicles, 300 heavy-duty vehicles, and 400 stationary or off-road hydrogen applications. The number of stations may remain the same at 250, however volumes of hydrogen dispensed at these 250 hydrogen stations will be increased significantly due to the expanded fleet of hydrogen vehicles in the state.

6.2 How to Deploy the Network

A well-planned strategy for building hydrogen stations is critical to creating a network that best serves the citizens of California. The strategy recommended for the CA H2 Net provides maximum benefits to the state without siting hydrogen stations prematurely, and it creates a network that serves the state both now, as hydrogen use increases, and in the future, as hydrogen vehicles and other applications become widely available. The Advisory Panel and Topic Teams recommend the following strategy for deploying hydrogen vehicles and infrastructure:

Build Fueling and Energy Stations

- *Expand the CA H2 Net to Serve Vehicle Population*. Closely coordinate development of hydrogen fueling infrastructure with deployment of hydrogen vehicles, and adapt and expand the network as the vehicle population grows.
- *Build Stations Based on Agreements with Energy Suppliers and Vehicle Manufacturers*. The State and public-private partnership should work together to strategize and establish agreements for building hydrogen stations.
- *Utilize a Mix of Production Pathways*. A mix of production pathways that reflect the diversity of production options that meet the environmental guidelines and work toward the long-term goals of the CA H2 Net should be utilized. This strategy provides flexibility to test a broad range of production methods in order to maximize experience gathering and allow superior pathways to evolve.
- *Leverage Resources and Experiences.* Work with other agencies, states and countries to leverage resources and experiences (e.g., other demonstration programs such as those of the U.S. DOE and the SCAQMD.)
- *Communicate Station Experience.* Put in place strategies that widely communicate information from experiences with hydrogen stations. This communication should foster public acceptance and spread knowledge that will assist in more efficient implementation of codes and standards to the jurisdictional authorities, and help establish real-pricing of hydrogen and insurance rates.
- *Coordinate with the State Fire Marshal and Permitting Officials.* Coordinate closely with the State Fire Marshal and permitting officials through implementation of the CA H2 Net. This strategy will be key in streamlining the station siting process and building knowledge to support future stations.
- *Communicate with the Community.* Perform community outreach, and provide technical programs where appropriate, as soon as planning begins for individual fuel stations. This strategy will help local stakeholders and the community become familiar with and support hydrogen stations in their neighborhood.
- *Utilize, to the Extent Possible, Lessons from Previous Alternative Fuel Deployments.* Based on the experiences from electric vehicles, methanol, and natural gas, the state should analyze, incorporate, and emulate the successes

achieved during these introductions. California has been one of the most active proponents in the world for clean, alternative fuel deployments. Many staff from different state and local agencies participated in these efforts and their experience should be utilized.

- *Encourage Improved Industry-University-National Laboratory Involvement.* The State, industry, and stakeholders should work closely with researchers in hydrogen, fuel cells, and renewable technologies in both the university system and national laboratories. California is home to world renowned researchers in these technologies, and their involvement will contribute greatly to station siting models, stationary fuel cell development, renewable hydrogen distributed production, and storage advancements.

Procure Vehicles and Other Hydrogen Applications

The "chicken or egg" conundrum for hydrogen cannot be solved unless simultaneous and coordinated efforts are made in deploying both stations and vehicles. As part of the CA H2 Net strategy, it is recommend that support of hydrogen vehicles and other hydrogen applications as the infrastructure be established. The Advisory Panel and Topic Teams recommend the following actions to support hydrogen products:

- *Include Hydrogen Vehicles in the State Master Services Agreement.* The State should support commercialization of hydrogen vehicles by incorporating them into the Master Services Agreement process as they become available. The Master Services Agreement process establishes pre-negotiated contracts to procure vehicles for government fleets, and inclusion of hydrogen vehicles would be an excellent way for the State to lead by example.

- *Encourage Non-State Fleets to Buy Hydrogen Vehicles*. Develop strategies and agreements to encourage non-government fleets to procure hydrogen vehicles. Fleet-based strategies in local and regional governments, as well as private fleets, can potentially build demand and accelerate the commercial sustainability of hydrogen vehicles.

- *Work with the CaSFCC and Trade Associations to Advance the Use of Energy Stations*. Close collaboration should take place with the California Stationary Fuel Cell Collaborative (CaSFCC) and industry trade associations to expand the use of stationary hydrogen applications in California.

- *Implement Policies that Incentivize Hydrogen Applications*. Adopt policies that incentivize hydrogen-fueled vehicles, stationary, and other feasible hydrogen applications to help establish the "early adopter" market for hydrogen.

6.3 Where the Stations Should Be Sited

- *Focus Infrastructure in Areas with High Utilization.* Site initial infrastructure in the highest expected vehicle population centers, such as Los Angeles, Sacramento, San Francisco and San Diego, as well as the regions between these population centers, such as the San Joaquin Valley. These locations will achieve the greatest use, and will provide valuable data that will help advance technology.

- *Maximize Synergy in Hydrogen Stations and Existing infrastructure*. Existing natural gas infrastructure meeting select criteria should be expanded to produce and deliver hydrogen. Many natural gas fueling stations in California would provide excellent structures to incorporate hydrogen because they already have high-capacity pipelines in place, experience handling and distributing compressed and liquefied gases, and they can be adapted to produce and deliver hydrogen on-site. Likewise existing hydrogen generation and fueling assets, such as merchant hydrogen and pipelines, should be leveraged.
- *Follow Station Siting Criteria*. Hydrogen stations should be planned according to the station siting criteria established for the CA H2 Net by the Blueprint Rollout and Strategy Topic Team. In order to ensure the best projects and sites are chosen throughout the project timeline for the CA H2 Net Initiative, potential sites should be screened based upon a series of criteria that fall into the general categories outlined in the Rollout Topic Team Report. For detailed siting criteria and "Screening Questions for Host Partners," please refer to the Blueprint Rollout and Strategy Topic Team report.

6.4 The Cost of Phase 1 of the CA H2 Net

The CA H2 net should be funded through a partnership between industry and government. The transition to a hydrogen economy is in the public's interest; therefore, government should play a key role and take responsibility for a longer-term focus than what industry may be compelled to do for shareholders. This longer-term vision requires an up-front investment in research, development and demonstration of hydrogen technologies, which will deliver multiple benefits to California.

The Advisory Panel and Topic Teams recommend the following hydrogen vehicle and infrastructure incentives:

- *Provide Hydrogen Infrastructure Incentives.* Funding to complete the first 100 stations should be shared between the State and the private sector.
- *Provide Hydrogen Vehicle Incentives.* Vehicle incentives should be provided by the State during Phase 1 to help ensure that 2000 vehicles are placed on California's roads over the next five years.
- *Identify Incentives to Reduce Investment Risk*. Identify industry and government agency incentives (financial and other) to reduce the risk and uncertainty to all stakeholders.

6.5 Who Should Implement the Hydrogen Highway Network?

The public-private partnership that was formed to develop the Blueprint Plan was a unique and extremely diverse group of representatives collaborating on a shared vision of a hydrogen economy. If maintained and leveraged, this partnership can be the driving force that can make the CA H2 Net successful – these stakeholders are the entities that are developing new technologies, building stations, manufacturing cars, developing stationary applications, demonstrating hydrogen vehicles and applications, establishing policies, and performing other functions that provide the foundation of a hydrogen economy.

It is recommended that a formal entity and working relationship be created to provide a structure for the public-private partnership to work together on the implementation of the CA H2 Net. This entity should:

- Work closely with Cal/EPA to implement the CA H2 Net.
- Establish its own governing rules
- Build upon and strengthen constructive involvement of CA H2 Net stakeholders
- Attract and coordinate the combination of public and private sector resources to accelerate the early growth of the CA H2 Net
- Work with the Cal/EPA to establish public-private partnerships in each metropolitan region, with wide stakeholder participation in each region, and active information sharing by all regions
- Help steer and adapt the CA H2 Net based on observations and lessons learned
- Investigate opportunities to integrate California Performance Review
- Consider legislation, policies and EOs to foster development of CA H2 Net

6.6 *Actions that are Necessary*

The Advisory Panel and the Topic Teams also identified a number of key actions that will be necessary to implement the CA H2 Net. These include work on codes, standards and permitting, emergency response and safety issues, insurance and liability schemes, and public education and outreach. Several of these key action areas included recommendations for legislative action. A summary of these recommendations is pulled out at the end of this discussion for reference.

Implement recommendations on permitting, codes and standards

As described in the findings of the Rollout Strategy and Implementation Topic Teams the process of siting and permitting hydrogen stations is new ground for many stakeholders and permitting officials. Clearly identified is the need for clarification of responsibility, uniformity of process and education of officials. The following specific recommendations were made:

- *List Hydrogen as a Transportation Fuel.* List hydrogen as a transportation fuel in the same manner that gasoline, diesel, and natural gas are listed. This designation would clearly define hydrogen as an acceptable substance to be used as a motor fuel. It would help direct permitting for hydrogen facilities to proceed along a similar path as other transportation fuels, while still allowing the unique characteristics of hydrogen to be taken into consideration by permitting officials.

- *Designate the State Fire Marshal as the Lead Authority Having Jurisdiction*. The Governor and/or Legislature should designate the State Fire Marshal as the lead coordinating authority having jurisdiction (AHJ) for the CA H2 Net, and amend the existing appeals process should be amended so that the State Fire Marshal's ruling is binding and final. These measures would provide a single overarching authority for issues related to hydrogen codes and standards, making the State Fire Marshal responsible for adopting hydrogen codes & standards, coordinating local AHJs and their permitting processes, and training emergency first responders to address hydrogen incidents.
- *Assist Local Jurisdictions in Appointing a Lead Coordinating AHJ*. Develop a strategy to assist local jurisdictions in appointing a lead coordinating AHJ for permitting hydrogen stations. Local jurisdictions have ultimate permitting authority for hydrogen fueling facilities, however, multiple agencies often issue permits within a local jurisdiction. A coordinating AHJ would help streamline the local permitting process and ensure all of the locality's permitting requirements are understood and met.
- *Initiate an Annual Hydrogen Code Cycle Review for Hydrogen.* The Governor should instruct the Building Standards Commission to initiate an annual hydrogen code cycle review beginning Mid-July 2005. This would ensure that California's codes and standards are kept current with advances in technology.
- *Reference Existing Standards*. While anticipating the adoption of newly developed, revised, or modified model building and fire codes for hydrogen stations, it is recommended that AHJs, through the permitting process, utilize by reference and as allowable under current law, the existing International Code Council (ICC) and/or National Fire Protection Association (NFPA) hydrogen codes.
- *Provide Means to Recoup Costs for New Responsibilities.* As the State Fire Marshal and designated local AHJs are given new hydrogen responsibilities, the State should provide them with the means to recoup the costs of those new activities.

  Support Federal Activities Involving Hydrogen Codes and Standards. The state should support, and to the extent possible, collaborate with the United States Department of Transportation in the development of Federal Motor Vehicle Safety Standards and other hydrogen safety and transportation standards.
- *Develop and Implement Three Templates*. The State Fire Marshal should be assigned responsibility for developing and overseeing uniform application of three templates: Template one would define responsibilities of relevant AHJs; template two would set forth the permitting and approval processes for hydrogen fueling stations, and; template three would describe the design requirements for hydrogen stations.

Implement Insurance and Risk Management Measures

Until there is a large statistical database of performance of hydrogen fueling stations, insurance companies may not be able to underwrite stations at affordable rates. The absence of clearly defined risk assessment and risk management measures may exacerbate this problem. Since these conditions may be a barrier to the implementation of the CA H2 Net, it is recommended that the State enact measures to ensure public safety and help provide reasonable rates for insurance. The following measures are recommended.

- *Include Risk Management Provisions in Handbooks.* Develop a strategy to ensure AHJs include comprehensive risk management provisions in the recommended hydrogen fueling handbook. The handbook would be available to station providers and permitting officials as a means to clearly identify state and local requirements and protocol for developing hydrogen stations.
- *Utilize Federal Hydrogen Safety Training.* Encourage the State Fire Marshal to utilize training offered by the U.S. Department of Energy's HAMMER (Hazardous Materials Management & Emergency Response) facility, and the U.S. Department of Transportation's Transportation Safety Institute.
- *Require the Inclusion of Risk Elements in Permitting.* Require all entities planning to build hydrogen-fueling stations to include specific elements related to risk assessment and risk management in their permitting submittals.
- *Create a Hydrogen Experience Database.* Create a State-run system to record and investigate safety-related incidents and offer a database of experience. This database would be made available to the insurance industry to reference and use in building the necessary body of statistics needed to provide affordable insurance rates.
- *Establish an Insurance Pool.* Establish an insurance pool, as has been done for underground fuel storage tanks and brownfields, to provide partial coverage of deductibles and set requirements for station installers and operators to self-insure. This action would help mitigate the insurance uncertainty associated with the lack of long-term statistical experience.

Perform Public Outreach and Education Activities

The success of the CA H2 Net is dependent upon Californians' understanding of the importance and value of moving toward a hydrogen economy. Lack of understanding is currently significant and will be a hindrance to public and political acceptance of the CA H2 Net if not addressed. Public communication is a continual process requiring a formalized approach and structure to carryout activities. The following actions are recommended.

- *Communicate to Target Audiences.* Direct communications actions toward four key audience categories: (1) hydrogen technology and industry enablers; (2) government, policy makers and influencers; (3) consumers and customers; and (4) educational institutions;
- *Establish a single point of contact.* Establish a single point of contact for each of the key audiences;
- *Organize a Major Public Education Campaign.* Organize a major, public-private advertising campaign immediately. The campaign should build

understanding of the value of moving toward a hydrogen economy, and promote acceptance of hydrogen technologies in transportation and non-transportation applications;

- *Leverage other Programs.* Leverage and collaborate activities with other communications programs;
- *Communicate Early in Station Siting Communities.* Coordinate early communication and education with communities where fueling stations are planned;
- *Control the Message.* Control the message to avoid "selling too much too soon";
- *Link with Sustainable Systems.* Demonstrate prominent linkage in all activities between hydrogen and systems that are renewable and sustainable;
- *Support Hydrogen Safety Training for First Responders.* Support the establishment of first responder curricula for fire science courses at the community college level, and ongoing courses for existing fire fighters and EMT personnel, that focus on hydrogen, fuel cells and hydrogen internal combustion engine vehicles.
- *Implement all Other Recommended Strategies.* Implement other communications activities directed toward each target audience, recommended in the Public Education Topic Team report.

Legislation

A summary of actions above that require legislation follows:

- Establish hydrogen as a "transportation fuel"
- Create an insurance pool for station owners
- Designate the State Fire Marshal's Office as the lead agency responsible for adopting hydrogen codes and standards, coordinating local authorities having jurisdiction and their permitting processes, and training emergency first responders to address hydrogen incidents
- Amend the appeals process for station siting so that the decision of the State Fire Marshal's Office on an appeal is binding and final

6.7 Establish and Ensure Environmental Guidelines

Because hydrogen can be derived from a variety of sources, some carbon based and others free from carbon and other pollutants, uncertainty exists among experts as to whether a hydrogen highway will provide the societal benefits required. It is for this reason that it is recommend that the following environmental guidelines be established to ensure the CA H2 Net provides maximum benefits to the state:

- *Reductions in Greenhouse Gas (GHG) Emissions.* Put in place measures to ensure the CA H2 Net provides, in the aggregate, an initial 30% reduction in GHG emissions relative to conventional gasoline and diesel vehicles, and gradually increase reductions in subsequent years. Additionally, the use of low GHG electrolysis pathways should be established, in cooperation with stakeholders.

- *Create a Renewable Portfolio Standard for Hydrogen.* Establish a Renewable Portfolio Standard for hydrogen, which should initially utilize 20% renewable resources in the production of hydrogen and gradually increase in subsequent years. Any electricity generated from renewable resources and counted toward the CA H2 Net should not be used to meet any other renewable obligation.
- Start now with a mix of production options that reflect the diversity of production options and the long-term goals of the CA H2 Net effort
- *Compliance with Criteria and Toxic Emission Standards.* Require compliance with all of the state's aggressive goals and requirements for criteria and toxic pollutants.
- *Evaluate Impacts.* Evaluate localized as well as regional impacts from hydrogen production pathways to ensure there are no negative external impacts to local communities

It is crucial that measures be established to ensure these environmental guidelines are adhered to. Further, the environmental guidelines must be paramount in the policies and funding plans for the CA H2 Net, including providing funding (if necessary) to offset differential costs of using renewable pathways in the development phase.

7.0 Glossary

Definitions

Authority Having Jurisdiction (AHJ) — The phrase "authority having jurisdiction" is used in code documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional government department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction. The AHJ typically assures compliance with a regulation, code or standard. In the absence of locally recognized codes a precedent is usually sought either from a similar application or a document used by another jurisdiction.

California Building Standards Commission (CBSC) — Charged with reviewing and approving building standards proposed for adoption by relevant state regulatory agencies. Composed of the Coordinating Council and the Code Advisory Committees

Code (Model Code) —Set of broad technical system requirements usually dealing with safety and/or performance of an overall system – established by professional Code Development Organizations (CDOs, e.g., ICC, NFPA) – non-mandatory. Model Codes incorporate by reference various standards. For example, the ICC Building Code incorporates standards published by 50 different organizations (ASTM, NFPA, UL, etc.). Stationary facilities are generally specified by codes and the equipment/process standards that individual codes reference. Comprehensive Model Codes may be adopted by regulatory agencies and, thereby, incorporated into law / regulation, and become mandatory.

Code Advisory Committees — Advises the California Building Standards Commission on proposed building standards by annually reviewing the technical merit of building standards as proposed by regulatory state agencies, and submit recommendations to the CBSC. There are five Code Advisory Committees: the Accessibility Committee; the Plumbing, Electrical, Mechanical, and Energy Committee; the Building, Fire and Other Committee; Structural Design/Lateral Forces Committee; and the Health Facilities Committee.

Coordinating Council — One of two bodies of the California Building Standards Commission. The Coordinating Council submits recommendations for building and fire codes and regulations, and is comprise of representatives of: Health Services, Office of Statewide Planning and Development, Housing and Community Development, Industrial Relations, State Fire Marshal, California Energy Commission, and General Services.

Control Recovery Register — Provides overall project details such as information on site equipment and operations measures

Distributed Generation (DG) — The generation of electric power and thermal energy at the location where a substantial fraction of the product is used. In general, DG is in the electric power range from a few kilowatts to 50 megawatts."

Emergency Response Plan — Detailed plan of execution should an emergency incident occur

Energy Station —An energy station is designed first and foremost for the distributed generation (DG) of electric power and a waste heat recovery thermal product (e.g., heat and/or cooling) delivered to a local customer. Three attributes distinguish an "Energy Station" from a stand-alone "Hydrogen Refueling Station:" (1) The DG is operated on natural gas or alternative fuels such as digester gas, land-fill gas, or bio-mass gas; (2) the principal commercial products are the export of electricity, thermal energy to a local customer or the grid and of hydrogen for vehicle refueling, and (3) the export of electricity and thermal energy is a commercially economically viable enterprise.

HazOp — Detailed design review process to ensure safe design and operation

Hydrogen Refueling Station — A station designed to dispense hydrogen fuel. Refueling stations can be either associated with energy stations or stand alone. As a stand alone, the station may include DG for balance of plant load leveling and, depending on the DG, to (1) meet critical system electrical supply needs, (2) serve as back-up power, and/or (3) serve as peaking power. In contrast to the energy station, the DG in the stand-alone scenario is fueled by hydrogen.

Implementation Topic Team (Team) — One of five Topic Teams contributing to the development of the Blueprint Plan describing how California should develop a network of hydrogen fueling stations by 2010. The Implementation Team addresses issues related to hydrogen codes and standards, and insurance and liability.

Law or Legislative Act — Broad set of legal requirements with no technical details on the subject matter.

Office of the State Fire Marshal (SFM) — A division of the Department of Forestry and Fir Protection dedicated to fire prevention. Responsibilities include: regulation of occupied buildings; managing flammable substances; regulating liquid pipelines transporting hazardous materials; reviewing regulations and building standards; and educating and training officials in fire protection practices.

Regulation — Set of legal requirements to support a Legislative Act or Law. May incorporate reference to technical codes and standards – mandatory

Site Quantitative Risk Assessment (QRA) — A risk management/assessment procedure which measures selected site risk such as the extent and frequency of hazards

Standard — Set of technical requirements, usually dealing with safety and/or performance of equipment or the installation of equipment Mobile/portable products are generally specified by standards. Some standards may be incorporated into local or federal regulations, and thereby become mandatory.

Standards Development Organizations (SDOs) — organizations of professional, technical experts that establish professional, non-mandatory standards to insure safety, compatibility, performance measures, and other features of equipment and processes; e.g., IEEE, CSA America, CGA)

Source-to-Wheels (STWs) — A type of analysis that fully assesses the environmental impacts of a fuel pathway and vehicle technology combination, by assessing the entire life-cycle of all processes, from the beginning of fuel production to the end use of the vehicle. This process is often referred to a "well-to-wheels" analysis when specifically focused on petroleum fuels. This document uses the term "source-to-wheels" due to the fact that not all hydrogen production involves initial pumping of energy resources from oil or gas wells.

Templates — Guidelines and provisions set forth as recommendations by the Implementation Topic Team to help ensure uniform application of codes and standards for the purpose of facilitating the permitting and installation of hydrogen fueling stations in California.

Acronyms

AHJ	Authorities Having Jurisdiction
ANSI	American National Standards Institute
AQMD	Air Quality Management District
ARB	California Air Resources board
ASME	American Society of Mechanical Engineers
ATR	auto-thermal reforming
BPV	Boiler Pressure Vessel
C&S	Code(s) and Standard(s)
CalEPA	California Environmental Protection Agency
CA H2 Net	California Hydrogen Highway Network
CaFCP	California Fuel Cell Partnership
CalOSHA	California Occupational Safety and Hazard Agency
CalTrans	California Department of Transportation
CARB	California Air Resources Board

CaSFCC	California Stationary Fuel Cell Collaborative
CBSC	California Building Standards Commission
CCR	California Code of Regulations
CDO	Code Development Organization
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CCHP	Combined Cooling, Heating, and Power
CH_2	Compressed Hydrogen Gas
CH_4	Methane
CNG	Compressed Natural Gas
CO	carbon monoxide
CO_2	carbon dioxide
DOE	United States Department of Energy
DOSH	California Department of Industrial Relations' Division of Occupational Safety and Health
DOT	United States Department of Transportation
EER	energy economy ratio
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EO	Governor's Executive Order
EPA	U.S. Environmental Protection Agency
FCV	Fuel Cell Vehicle
FMEA	Failure Mode and Effect Analysis
GHG	greenhouse gas
H_2	hydrogen
HAMMER	US Department of Energy's Hazardous Materials Management & Emergency Response Facility
HAZMAT	Hazardous Materials Safety
HCNG	hydrogen and compressed natural gas
HDV	heavy-duty vehicles
HICE	Hydrogen Internal Combustion Engine
HSM	hydrogen separation membrane
ICC	International Code Council
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
KOH	aqueous potassium hydroxide
LH_2	Liquid hydrogen
LNG	Liquefied Natural Gas
N_2O	nitrous oxide
NO_x	oxides of nitrogen
NEPA	National Environmental Protection Act
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Testing
NPRM	Notice of Proposed Rulemaking SFM
NRTL	Nationally Recognized Testing Laboratory
OAL	Office of Administrative Law

OEM	original equipment manufacturer
OSFM	Office of the State Fire Marshall
PEC	hydrogen-production process
PEM	proton exchange membrane
POX	partial oxidation
PM	particulate matter
PPP	public-private partnership
PSA	pressure swing adsorption
PUC	California Public Utilities Commission
PV	photovoltaic
PZEVs	Partial Zero Emission Vehicles
QRA	Site Quantitative Risk Assessment
RA/M	Risk Assessment and Risk Management
ROG	reactive organic gases
ROP	Report on Proposals
RPS	California's Renewables Portfolio Standard
RSPA	U.S. Department of Transportation Research and Special Programs Administration
SAE	Society of Automotive Engineers
SCAQMD	South Coast Air Quality Management District
SDO	Standard Development Organization
SMR	steam methane reforming
SPE	solid polymer electrolyte
UFC	Uniform Fire Code
UL	Underwriters Laboratories
VTA	Santa Clara Valley Transportation Agency
WTW	Well-to-wheel