

**A Hydrogen Fueling Station in 2005 – Will it Happen?
How do we get from Here to There?**

By

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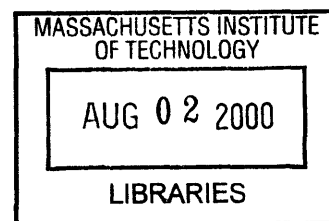
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Fuel cell vehicles appear promising for major reductions in local emissions and significant decreases in greenhouse gas emissions from the transportation sector. Efficient fuel cells require hydrogen fuel. If the hydrogen is produced from primary fossil fuel sources, the greenhouse gas benefits are much reduced; full benefits require hydrogen as the onboard fuel - and production of the hydrogen with few or no greenhouse gas emissions. Experience with hydrogen fueling and infrastructure will be important to the long-term success of fuel cell technology. This thesis examines the first steps, barriers and opportunities, and the various strategies to transport hydrogen from the source to the fuel cell. The sources of hydrogen have been thoroughly evaluated, the methods of reforming the source to pure hydrogen are commercially available, and there are several models of fuels cells that are developed to the point where they can be demonstrated in fleet vehicles. What remains to be put in place is an infrastructure to deliver the hydrogen to the fuel cell, an initial system demonstration to build safe operational practices, and a progressive plan to complete the picture of alternate fuel technology to convince the public that this alternative to fossil fuels is technologically practical. In conclusion, this thesis describes an evolutionary plan to transfer bus fleet fuel first to natural gas and then to hydrogen. Initial demonstration will use liquid hydrogen to allow the demonstration of a hydrogen system of fuel for fleet use within five years. Longer term, fueling stations are likely to reform natural gas from the existing pipelines to provide high-pressure hydrogen for wider fueling applications.

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Introduction

The transition to hydrogen as a transportation fuel presents an interesting dilemma in which an attractive technology is feasible, the motivation is apparent, key participants are present, and government funding is available. However, the heart of the support system required for successful implementation within the next five years is non-existent. Industry, government, and society must reevaluate the current process and level of technology to determine the appropriate strategy for alternative fuel usage. This strategy should be focused on the long-term benefits to the air quality and to the environment as a whole. The present outlook for re-engineering our transportation system to use alternative fuel sources is dim. There are seemingly insurmountable obstacles in the form of cost and contemporary transportation expectations, which view alternative fuel transit as restrictive and inflexible.

This thesis discusses the various strategies to transport hydrogen gas from the primary source (fossil fuel or water) to the fuel cell. The sources of hydrogen have been evaluated, the methods of reforming source fuels to pure hydrogen have been commercially demonstrated, and there are several model fuels for fuel cells that have been developed to the point for fleet demonstration. What remains to be put in place is an infrastructure to deliver the hydrogen to the fuel cell and a transition plan that will convince the public that this alternative to fossil fuels is technologically practical, economically viable, and environmentally sound.

Natural gas fuel technology with the reformer at the vehicle-fueling site was chosen as the most practical infrastructure design to ensure a consistent and reliable stream of hydrogen from source to reformer to fuel cell. Natural gas is plentiful and available in most parts of North America. Natural gas contains few contaminants, its transport technology is sophisticated and safe, and it should not raise public apprehension. A number of efficient methods to strip hydrogen from methane already exist and are used in industry. Reforming natural gas at a refueling station enables the distance from the fuel supply to the reformer to be shortened. The hardware for hydrogen transport is the least developed and the most critical to the success of implementation.

An initial demonstration is planned with a bus fleet and a single fuel station. Liquid hydrogen may be used for the phase demonstration. The evolutionary plan is to transfer from natural gas to hydrogen as a fleet fuel. Building the infrastructure needed to change from natural gas to hydrogen is relatively simple. A reformer can be placed at the end of the gas pipeline and a high-pressure hydrogen system can then fuel the vehicles.

Fuel cell technology is sufficiently developed to be installed and evaluated in fleet vehicles with a reasonable expectation of success. Field tests of several bus fleets located in

different climates and in North America have demonstrated the technical practicality of fuel cells powering large buses. There are several proven methods of producing. Natural gas can be transported to a reformer site with current technology. Some engineering problems with the storage, transport and transfer of hydrogen to the fuel cell vehicle remain and must be resolved and in a reliable way. The initiation and successful evolution of a fuel cell program also hinges on training participants at all levels of the experiment. Training fleet operators is essential and active management is mandatory. Specific attention must be paid to the training and education of all individuals who operate and manage alternative fueling stations. Any accident or malfunction during the early stages of demonstration would pose a serious set back in public perceptions of hydrogen technology. Any program must be carefully designed, implemented, and monitored to ensure safety and success.

A commercial hydrogen fueling station is a real possibility in the near future. Short-term difficulties may be easily resolved through the use of subsidies to alleviate capital and financial burdens. Most new technologies are subsidized and go through a steep learning curve before introduction. Hydrogen fuel cells are no exception to this rule. Introduction of a hydrogen fueling station will require a decision by government, industry, and society to that if the technology is desirable. The introduction of a hydrogen fueling station within the next five years offer a grounded way to explore the implications of this choice. A long-term plan will require demonstration of the application and feasibility of the technology to work satisfactorily. The sooner experience is gained facilitating the change to a hydrogen fueling system; the easier future transition to a hydrogen energy economy will be. Any hope of reducing greenhouse gas emissions must begin with a significant reduction of pollution. In meeting greenhouse gas emission standards, hydrogen fuel cell buses are an attractive alternative. If society embraces hydrogen as the best available method to decrease emissions, then the demonstration of the technology will provide us with the experience required for a more rapid introduction.

Creating strong environmental policies and the successful implementation of technological innovation requires the *willingness* of society to change, the *opportunity* for the introduction of technology, and the *capability* of that technology to be easily diffused in society with minimal disturbance to the way we live. Strong leadership, enthusiasm, motivation and commitment, are all key elements of success. The successful introduction of innovative technologies requires a strong determination of all individuals, access to adequate levels of funding, appropriate and feasible technology, and the infrastructure required to support implementation.

Chapter 1: The Promise of Hydrogen

1.1 Background

Demand for alternative sources of fuel has increased substantially over the past decade. In the United States, the state of California has been primarily responsible for increasing environmental standards for vehicle emissions. Recent legislation requires that ten percent of all new vehicles sold and operated in California be Zero Emission Vehicles (ZEV) by 2004. The regulatory agenda increased demands on vehicle manufacturers to either choose an alternative fuel or to redesign vehicle propulsion systems (such as electric vehicles). Hydrogen is one alternative fuel that meets zero emission standards. Electric vehicles have range and cost barriers largely associated with bulky batteries. Fuel cell vehicles with on-board reformers to convert liquid fuels to hydrogen are not true ZEV's. A hydrogen-fueled fuel cell vehicle would meet the ZEV criteria, however it is the focus of this thesis to explore the initial infrastructure necessary that will support the development of a hydrogen fuel experimentation.

The technical characteristics, economic feasibility, and infrastructure requirements of fuel cell engines and vehicles are impacted to varying degrees by the particular fuel types chosen. Fuels presently being considered for transportation applications are hydrogen, methanol, natural gas and gasoline-related petroleum distillate fuels. Therefore the choice of fuel is of prominent importance to any program that will develop and eventually commercialize automotive fuel cell technology.

There are several major issues surrounding the use of hydrogen as a vehicle fuel. Storage of adequate amounts for vehicular use and general availability at acceptable cost are two dominant issues regarding the use of hydrogen as fuel. However, research conducted on the transportation, distribution, or sale of this fuel is minimal and to date has not fully addressed the political or social constraints that impede the development and eventual implementation of hydrogen fuel.

To outline the preliminary steps required for alternative fuel use, this thesis explores how to expand our current infrastructure from gasoline to an alternative fueling system. In this exploration, the thesis will analyze a specific fuel, vehicle, and location. Los Angeles has been chosen as an appropriate area to explore these questions since demands to address this issue already exists, there is an obligation to meet state emissions targets, and a large public transportation system is already experimenting with alternative fuels. If alternative fuel vehicles are eventually to be put in widespread use, Los Angeles is likely to be the first city in which they would be implemented.

The simplest initial step toward hydrogen is as an alternative fuel for fleet vehicles. This thesis examines the hydrogen fuel infrastructure for a bus fleet. The movement toward alternative transportation fuels in general and hydrogen vehicles in particular, faces intense opposition from the automotive and oil industries and to a lesser extent, from a public concerned with cost and safety. Companies such as Exxon, Arco, Ford, General Motors, and Daimler-Benz have been conducting extensive research into the development of alternative methods and resources to create a sustainable energy and transportation system for the future. Transportation is where society's environmental, energy and economic problems are most severe, where the rationale for changing the status quo are most compelling, and where opportunities to develop consumer support are strongest.

The ultimate merging of energy needs and population growth – through electricity production and increased transportation needs – appear inevitable in the next century as automobiles are converted to electric energy and fossil fuels are replaced with renewable resources. If hydrogen is to be used as a transportation fuel the impact of an entire life cycle must be assessed. The production and distribution of hydrogen are essential components to an evaluation that must precede the eventual use of this technology. In spite of increasing population and transportation demands, new technology may facilitate a transition to a more viable and sustainable energy source.

1.2 Objective

The objective of this thesis is to analyze the practical steps necessary to support a system of hydrogen fuel cell buses. It will examine what must occur in the next five years as a way to demonstrate that a hydrogen fueling station is a practical option for Los Angeles. Widespread use of fuel cell vehicles will require the introduction of an alternative fueling infrastructure. Initially this infrastructure will supplement the current internal combustion engine and its supporting gasoline fueling stations. A detailed examination of the political and social ramifications of changing the fueling infrastructure is essential to understanding how the current fuel system infrastructure might evolve into a system based on hydrogen fuel.

1.3 Approach

If a large portion of the Los Angeles bus fleet was to be converted to hydrogen fuel cell buses, what would be required in the next five years to provide fuel to the fleet? To determine the requirements and actions necessary, it is essential that the regulatory and social issues faced by a

hydrogen fuel station in Los Angeles be addressed. This would also determine the optimum infrastructure needs for buses in the area, including production, distribution and the transportation of hydrogen.

Fuel cell vehicles are the “cleanest” with respect to ZEV criteria when they are fueled with hydrogen. Fuel cell technology is also attractive because of its efficiency and lack of noise. Fuel cells are an emerging technology that needs to be tested under real world conditions so that data regarding vehicle performance and fueling infrastructure may be gained. New hydrogen fuel infrastructure will be needed to support fuel cell vehicles.

The initial introduction of fuel cell vehicles will be in fleet use with a limited number of fueling stations; plans are currently underway for such a project in the Los Angeles area. This thesis assumes a time frame that would see initial implementation by 2005. It also examines the next stages required for subsequent development. Cost and safety are major issues that need to be resolved. Start up cost and safety measures require investments that will not immediately be cost-effective, but must be considered an investment in gaining expertise in the implementation of the new technology.

Hydrogen fuel can be stored either as liquid or compressed gas. Liquid hydrogen is the primary focus for this thesis as it is commercially available, and it seems a reasonable product for use as fuel. Since liquid hydrogen can be trucked to fueling stations, storage tanks and fueling systems are the only fuel-side equipment needed to start the activity. The simplicity of this initial step suggests it is reasonable that it could be in place by 2005. Over the longer term, private vehicles are likely to adopt this technology and ultimately a wider network of fueling stations will be required. Because availability of liquid hydrogen is limited and costs are relatively high, this larger network would probably rely on natural gas from the existing pipeline network and reforming it to compressed gas for use in vehicles. Storage of hydrogen is difficult and still impedes the broader use of fuel cell technology. Current research and development is searching for improved methods. A breakthrough in hydrogen storage technology would be a major catalyst for the introduction of this technology on a wider basis.

Introducing a hydrogen fueling station will make apparent which issues must be addressed in the next five years for the benefits of a hydrogen fuel cell bus to be realized. A case analysis examining the success of the SunLine Transit Agency demonstration project in the Coachella Valley of California will provide insight into the difficulties, successes, and cost involved in the transition of a bus fleet from compressed natural gas to hydrogen fuel cell buses. Production, distribution, and transportation requirements for hydrogen fuel are discussed briefly, but are not a major component of the case analysis since only a small amount of hydrogen fuel

will be required for demonstration, and it will be delivered to the site via truck. Questions about economies of scale for hydrogen use as fuel remain to be resolved.

Other demonstration programs are also analyzed for similarities and difficulties pertinent to the introduction of a hydrogen fueling station for fuel cell vehicles. The examination of natural gas and other alternative fuel fleet conversions shows the central role fleet managers play in promoting alternative fuel use and suggests the importance of a strong governmental push for compliance with increasingly strict emission standards. This thesis will also address the question of why acceptance of and conversion from gasoline to alternative fuels has been so slow when it is underpinned by strong science and supported by existing infrastructure? While economics and cost are significant impediments to the development and transition to alternative fuels, these barriers are attenuated in the case of compressed natural gas. Thus it represents a logical first step in the slow transition to more sustainable and efficient forms of energy supply. It can provide a model and act as a catalyst for the development, introduction and support of hydrogen as an energy system for the future.

Many concerns are raised by implementing a hydrogen fuel station for buses that could influence the design requirements for subsequent choices about technology and policy.¹ Technology must be able to make a smooth and subtle transition into society with little or no disruption to our lives. Policy and social objectives must be strict enough to promote the development of 'clean' technologies, while effectively establishing standards for safety and training. The immediate requirements for buses and long term objectives for individual vehicles will each require extensive demonstration since two have distinct uses and technological requirements. This thesis outlines the set of concerns that scientists, politicians, and private citizens must still address to establish a hydrogen fueling station for fleet usage by 2005 in the form of a strategic plan. If transit agencies lack a coherent understanding of the concerns about implementation described in this plan, the demonstrations being conducted worldwide might ultimately prove to have minimal impact on long-term development. The crucial determinant for success is to immediately begin strategizing how actions can balance human needs for transportation and environmental welfare. Strategic planning for fuel cell propulsion technologies will also determine whether or not the technology is viable. Can this alternative technology be

¹ Hydrogen based fuels could have far-reaching consequences for economy-wide production and consumption and lifestyles. This raises the important point that environmental technology innovations often result from radical innovations made in other technical fields (such as fuel cells). Improvements in environmental technology can be expected as a product of strong research/innovation culture, not just through specific environmental goals. This may be an important lesson for regulatory policy. Sylvie Faucheux, "Sustainability and Firms, Chapter Two: Globalization, Competitiveness, Governance and Environment: What Prospects for a Sustainable Development?" pg. 23.

transferred outside North America to become effective globally? Its ability to reduce our reliance on fossil fuels and reduce CO₂ emissions on a global scale will play a significant role in the introduction, acceptance and implementation of hydrogen fuel cell energy systems.

1.4 Structure of Thesis

This thesis is divided into seven chapters that address distinct aspects of the implementation of a hydrogen fueling station over the next five years.

Chapter two provides an overview of current fuel cell technology and discusses the concerns regarding the need for the establishment of an alternative fueling system for vehicles. A specific focus on hydrogen fuel cell vehicles is also discussed with a brief comparison of research on available alternative fuels. Chapter three analyzes conversion to natural gas as an intermediate step with the conversion of buses to hydrogen fuel. Chapter four details a case study that focuses specifically on Los Angeles as the optimal area for the introduction of a hydrogen fueling station. Environmental and political initiatives such as those of the California Air Emissions Reduction Board explain the urgent need to combat air pollution from transportation in the Los Angeles valley. Demonstration projects of alternative fuel buses such as the use of compressed natural gas in the SunLine Transit Agency project are outlined as a tool to demonstrate the commercial feasibility of fleet conversion to hydrogen fuel cell buses. Chapter five examines the system requirements for hydrogen energy. The energy system requirements for hydrogen are surrounded by issues and options pertaining to the production, distribution, and transportation of hydrogen as fuel. Chapter six outlines the relevant codes and standards that are required for the use of hydrogen fuel, and the regulation of training and management skills required by those dispensing, storing, and using hydrogen.

In order to realize the feasibility of a hydrogen fueling station in Los Angeles, or for anywhere in the world, a coherent and practical strategy for policy makers and transit agencies must be determined and implemented. Chapter seven is an outline of an immediate short-term plan. It focuses on hydrogen as the main energy carrier of the future and provides recommendations for the continued development and incorporation into society of a hydrogen fueling station.

Chapter 2: Alternative Fuels: The Demand for Hydrogen in Fuel Cells

2.1 Fuel Cells - Why Hydrogen?

Fuel Cells are electrochemical devices that convert fuel energy directly to electrical energy². Fuel cells operate much like continuous batteries when supplied with fuel to the anode (negative electrode) and oxidant (i.e. air) to the cathode (positive electrode). Fuel cells forego the traditional extraction of energy in the form of combustion heat, conversion of heat energy to mechanical energy (as with a turbine), and finally turning mechanical energy into electricity. Instead, fuel cells chemically combine the molecules of a fuel and oxidizer without burning, dispensing with the inefficiencies and pollution of traditional combustion. The extraordinary environmental quality (ultra-low NO_x, CO, Hydrocarbon, and noise emissions) and high efficiency of fuel cells can significantly contribute to the mitigation of environmental effects while meeting increasing energy demands.

Continued reliance on petroleum fuels, internal combustion engines, and end use technologies pose significant challenges with respect to air pollution, green house gas emissions, and energy supply security, particularly in the transport sector. Hydrogen produced from renewable resources offers perhaps the largest potential benefit in terms of reducing emissions of pollutants and greenhouse gas emissions while offering a diversified primary energy supply, but is also widely perceived as posing the largest technical and economic challenges. Despite the potential attractions of a zero emission hydrogen energy economy, the development of hydrogen energy infrastructure is often seen as an insurmountable technical and economic barrier to the use of hydrogen as an energy carrier. There is a problem amongst industry, academia, and governments who are all unable to make an educated decision on which path to take. All areas feel it is “too early to pick a winner among emerging advanced transportation technologies”.

² Fuel cells and fuel cell technology represent a fundamental shift in technology toward sustainable transportation solutions. The fuel cell is a device that converts the chemical energy of a fuel into usable electricity and heat without combustion as an intermediate step. Fuel cells are similar to batteries in that both produce a DC current by means of an electrochemical process. In both systems, two electrodes, an anode ($2\text{H}_2 \rightarrow 4\text{H}^+ + 4\text{e}^-$) and a cathode ($\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$), are separated by an electrolyte. Unlike batteries, however, fuel cells store their reactants (hydrogen and oxygen in air) externally, and operate continuously as long as they are supplied with fuel. At the anode, hydrogen atoms are split by a catalyst into hydrogen ions (protons) and electrons. The hydrogen ions then travel through the electrolyte to the cathode. Simultaneously, the electrons move through an external circuit to a load and then to the oxygen electrode ($2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{electricity} + \text{heat}$). There the oxygen, hydrogen ions, and electrons combine on a catalyst to form water ($2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$). Fuel cells emit almost none of the sulfur and nitrogen compounds released by conventional generating methods, and can utilize a wide variety of fuels if a fuel processor is used to release the hydrogen contained in them. Emissions occur from the fuel processor, but lower reformer temperatures produce less NO_x than internal combustion engines.

Firms are concerned about getting locked in to expensive environmental protection measures that become obsolete if regulations or market conditions change.³

It is important to differentiate incremental and comprehensive approaches from one another and both from the notion that the demands of development create a need for a program in which goals can be articulated, the significance of experience debated, coordination may occur, and learning may be confirmed.

“...Building alliances between the public, private and communal sectors, so that at least the contradictions between economic growth and environmental resilience can be addressed. When there is hesitation about future trends, a key factor for economic coordination becomes the development of collective alliances of government (national and international institutions), the private sector (trade and industry associations), and the people (consumer associations, non-governmental associations – NGO’s of all types) to promote an understanding and vision of the world along with new standards of conduct giving legitimacy to a given orientation.”⁴

Hydrogen fuel cell technology has attained levels of power density and efficiency adequate for automobile propulsion. If hydrogen were to become a practical, generally available and affordable fuel in the near future, complexity and cost could be reduced, thereby enhancing the prospect for successful automotive fuel cells.

Despite the fundamental attraction and widespread advocacy of hydrogen as a primary fuel for automotive fuel cells, the vehicle makers engaged in the development of fuel cell engines and fuel cell vehicles are considering a variety of fuels including hydrogen. For the moment, methanol is the fuel of choice. Toyota, Daimler-Benz, Ford and other leading developers have shifted their initial emphasis from hydrogen to methanol. In the timeframe of private sector programs, they do not see a resolution of the two major issues surrounding hydrogen: Storage of adequate amounts of fuel onboard automobiles, and the general availability of hydrogen at acceptable costs.

2.2 Fuel Choices and Issues

Given the issues and uncertainties associated with alternative fuels, it is not surprising that different developers of automotive fuel cell systems have made different choices. Many appear prepared to reconsider their current choice if there are new developments that affect the

³ Faucheux, Sylvie. “Sustainability and Firms” Chapter Two, North Hampton, US: Edward Elgar.

⁴ Faucheux, Sylvie. “Sustainability and Firms” Chapter Two, North Hampton, US: Edward Elgar.

major technical, economic and availability questions surrounding the choice of fuel. Table 2.1 lists the number of different types of currently available alternative fueled vehicles.

Table 2.1 Number of Vehicles by Fuel Type 1997

Fuel Type	Fuel Use (millions of equivalent gallons)	Number of Vehicles
Gasoline	120,100	155,000,000
Diesel	27,800	35,000,000
Propane	245	273,000
Natural Gas	86	82,700
Methanol (M85)	4	19,800
Ethanol (E85) & Biofuels	2	6,200
Battery Electrics	1	3,900
Hydrogen	<1	<20

Fuel Cell Use In U.S. Transportation 1997 (Source: James Cannon, "Clean Hydrogen Transportation: A Market Opportunity for Renewable Energy" April 1997 University of Maryland at College Park, Renewable Energy Policy Project. Issue Brief No. 7.

The choices these developers face have actual and potential impact on prospective availability, operating characteristics and competitiveness of fuel cell vehicles. To understand the effect of these, the key considerations driving fuel choice and the trade-off's between hydrogen storage on-board and hydrogen reforming must be examined.

Fuel cells operate best on pure hydrogen. Storing hydrogen on board a fuel cell vehicle greatly simplifies the propulsion system design by not requiring on-board fuel processing. It also results in a more energy efficient system. Because hydrogen is normally a gas, a relatively large volume is required to contain enough energy to provide the same driving range as today's automobiles. Currently, two methods of storing hydrogen on board a vehicle are receiving the most attention: namely, compressed gas in storage tanks at high pressure or liquid hydrogen in insulated storage tanks at low temperature and pressure. Other methods based on metal hydrides, solid absorbents, and glass micro-spheres have potential advantages but are not as well developed. Hydrogen storage systems can be engineered to be as safe as the fuel systems in current automobiles. However, the design of the storage vessel must incorporate the effects of varying temperatures (cooling and expanding) on the fuel cell that occur when operating in

elevated or decreased temperatures.⁵ To date, hydrogen fuel cells have been demonstrated to operate in various uncontrolled climates, such as Chicago, Thousand Palms, Vancouver, and Stuttgart (See Appendix 13 for a description of Chicago Transit Agency demonstration).

On-board reformers must make enough hydrogen to operate all of the facilities – air conditioning, radio, power windows, etc. – no matter what the climate. If the source of hydrogen is a liquid (with a reasonable boiling temperature) then the reformer becomes the best engineering option for the vehicle. However, if the reformer is neither able to make enough hydrogen to fuel the vehicle, or to provide it as fast as it is being consumed, then the reformer must run outside the actual vehicle operation and store additional hydrogen. Storing this hydrogen will require both a compressor and a pressurized tank. The on-board reformer then loses its advantage. A chemical-electrical-mechanical system that will require maintenance will also add to the overall cost of the vehicle.

The vehicle storage approach is mechanically more simple than the reformer, but the fuel capacity (i.e. mileage) is limited for a tank. The storage is ultimately a pressurized tank. Volume limitations are based on the given size and pressure capability of the tank. Engineers are currently experimenting with absorbents inside the tanks to reduce the pressure and allow more hydrogen to be stored.

2.2.1 Gasoline

Gasoline, of course, meets the cost and logistic criteria as an automotive fuel cell fuel and is an efficient, liquid “hydrogen carrier” of high energy density. However, compared to methanol, gasoline requires a somewhat more complex and less efficient chemical processing system for its conversion into a hydrogen-rich fuel gas stream. This is primarily because of the substantially higher temperature needed to chemically activate gasoline in the primary processing reaction. To date, gasoline fuel processors have seen less development for automotive applications and are less advanced than methanol processors.

The basic feasibility of processing gasoline into hydrogen-rich “reformat” has been established in several laboratories, but it is not yet clear whether ordinary pump gasoline will be compatible in practice with automotive fuel cell engines. Pump gasoline contains varying amounts of sulfur (in form of organosulfur compounds) and a variety of additives to promote clean burning of fuel in IC engines. Sulfur-tolerant fuel processor catalysts have been

⁵ http://www.ott.doe.gov/oaat/fuelcell_tech.html (Also refer the Chicago Transit Agency demonstration of hydrogen fuel cell buses)

demonstrated in laboratory and industrial operations but it is unclear at present whether the conditions used are transferable to automotive fuel processors. If sulfur — in the form of hydrogen sulfide because of the reducing conditions prevailing in the reformat — breaks through the primary processing reactor(s), the platinum catalyst of the reactor is likely to become deactivated by sulfide formation. If hydrogen sulfide also breaks through the reactor and enters the stack, the anode catalyst almost certainly will be deactivated for the same reason. At the temperature of the stack, sulfide formation will be largely reversible.

To protect the fuel cell engine from this possibility will require removal of sulfur somewhere in the fuel processor by a “guard” consisting of a zinc oxide bed. Such a guard would require monitoring and periodic replacement further complicating an already complex fuel processing system. Sulfur removal at the refinery is likely to be more cost effective once sufficient demand for a “near-zero” sulfur gasoline develops, but it is not yet clear to what extent sulfur would have to be taken out for assured gasoline compatibility with fuel cell engines.

Additives such as detergents, anti-oxidants and corrosion inhibitors also raise questions regarding their long-term compatibility with future fuel cell engines if their composition includes elements other than carbon, hydrogen and oxygen. Clearly, one solution to this issue is to not add these compounds in the first place, thus making the case for a “fuel cell-grade” hydrocarbon fuel as will be discussed below.

Most organizations focusing on gasoline for fuel cells advocate that petroleum distillate compositions suitable for fuel cells be determined and, ultimately, be produced at refineries for distribution to stations serving fuel cell electric vehicles. These compositions do not need to meet internal combustion engine requirements such as octane rating, Reid vapor pressure ratings, and boiling point ranges. They will, however, be required to meet the criteria for chemical compatibility of the fuel with the fuel processor, and compatibility of the reformat with the stack.

For a “fuel cell-grade” fuel, additives and high vapor pressure hydrocarbons are no longer required and are considered undesirable. As a result, the best petroleum-derived liquid fuel for fuel cells may simply be a distillate cut with relatively low vapor pressure from which sulfur compounds are removed to a sufficiently low, but as yet undefined level at the refinery. The lower vapor pressure compared with pump gasoline should result in lower evaporative emissions and an increase in fire safety. Any savings from the elimination of additives and octane-rating enhancing refinery processes could offset the cost of sulfur removal at the refinery in part or entirely.

2.2.2 Methanol

Methanol has been considered for fuel cell power generation for a number of years because it can be processed into a hydrogen-rich fuel gas with relative ease and efficiency by steam or autothermal reforming. Processing of methanol onboard a vehicle presents a number of difficult challenges. Nevertheless, most automotive fuel cell and fuel processor development worldwide is focusing on methanol, for both technical and long-term strategic reasons.

At the long-term average price of about \$0.80 per gallon of gasoline energy equivalent, methanol made from natural gas is more expensive than gasoline on tax free energy basis, but it is still an affordable motor fuel, especially when considering the high fuel efficiencies expected for future FCVs. The prospects for expanded supplies of methanol appear promising because it could become an increasingly important for transport of natural gas energy from many sources worldwide — including remote sources not accessible by gas pipelines⁷.

The establishment of a methanol distribution infrastructure is a more complex issue. *With the exception of a limited distribution capability for M85 (a blend of 85% methanol and 15% gasoline) in parts of California, there is no infrastructure for methanol automotive fuel distribution at present, and the methanol industry is not in the business of owning and operating fueling stations.* It is reasonable to assume, that alliances between the methanol industry and the distributors and retailers of gasoline could develop apace with the emergence of an automotive fuel cell market for methanol. Estimates for methanol production could be as follows: limited infrastructure (70,000 bbl/day capacity) investments for methanol production about \$3.2 billion (\$640 per car), full infrastructure (1.6 billion bbl/day) \$84 billion (\$720 per car). These numbers are marginally higher than the production plant investments mentioned by Methanex:⁸

- Between 1998 and 2004 methanol producing capacity in the world is expected to increase by approximately 5.6 million tons, or 16.3 percent. Global methanol increases in the same period of about 3.6 million metric tons or 13.9.

⁶ As noted below under Oil Industry Involvement, this possibility is of interest also to oil companies.

⁷ Since large volumes of natural gas are still being flared or vented at oil production sites, conversion of that gas to transportable methanol would have a double benefit with respect to undesirable releases of greenhouse gases to the atmosphere: the venting of methane, a highly effective greenhouse gas, would be reduced or eliminated, and a significant amount of oil/gasoline would be displaced by methanol made from natural gas that otherwise would have been burned without performing useful work.

⁸ Methanex – Annual Information Form – Business, <http://www.methanex.com/>

- The methanol industry continues to be directed by the “carrot and stick” syndrome, with continuing promise of increased demand for nontraditional uses.
- Despite superficial similarities, the significant chemical differences between methanol and gasoline mean that they can not share the same distribution system. The high miscibility of water in methanol result in methanol that is highly corrosive. Methanol also requires different installations because it presents a greater flammability hazard than gasoline when exposed to air within a confined space, as it might be in distribution terminals, service stations, or vehicle fuel tanks. While methanol can be handled safely, the equipment involved will differ from those that current gasoline infrastructure provides.⁹
- Methanol manufacturing consumes more energy than it takes to produce gasoline, diesel, naphtha, and other hydrocarbon fuels. The efficiency of even the newest natural gas based methanol plants is about 68-70% compared to 90% efficiency of crude oil refineries.¹⁰ Greenhouse gas emissions from the production of methanol may be no better than those of gasoline.

2.2.3 Natural Gas

The technology for producing hydrogen is available today but establishing a hydrogen transportation system could likely take several years, or even decades. Natural gas is a fossil fuel that offers substantial advantages over oil-derived fuels, but could also facilitate a transition to hydrogen fuel. Automotive fuels, natural gas and hydrogen are similar in several ways:

- Natural gas and hydrogen can both be burned in internal combustion engines.
- Hydrogen can be added to natural gas to make it burn more cleanly.
- Both fuels share similar automotive storage and refueling system technologies.
- Most manufactured hydrogen is currently extracted from natural gas.
- Hydrogen could be distributed through existing natural gas pipelines, and the construction of new pipelines to carry hydrogen could benefit from the existing “rights of way” for natural gas distribution.

Because of this overlap, investments to refine and expand the infrastructure for natural gas vehicles can also lay the groundwork for the use of hydrogen.

⁹ Berlowitz, Paul J., and Charles P. Darnell. “Fuel Choices for Fuel Cell Powered Vehicles,” Society of Automotive Engineers, Inc., 2000-01-0003.

¹⁰ Berlowitz, Paul J., and Charles P. Darnell. “Fuel Choices for Fuel Cell Powered Vehicles,” Society of Automotive Engineers, Inc., 2000-01-0003.

2.2.4 Hydrogen

Hydrogen is the earth's most abundant element found in both water and biomass. Hydrogen production in 1993 in the United States alone was over 5 billion cubic meters (178 billion cubic feet). Most of this production is used in ammonia production and in the stripping of sulfur from petroleum during the refining process. One of the largest consumers of pure hydrogen is NASA.

The entire energy system must be considered when assessing alternative pathways for producing and using hydrogen.¹¹ Methods of production, distribution, and transportation must be heavily considered prior to the development and introduction of a hydrogen fueling station. "Hydrogen is in the early phases of historical development, and several decades of intensive technical development and adaptation in terms of energy economics and marketing transition lie ahead"¹².

Hydrogen is a high quality, low polluting fuel that can be used with high efficiency for transportation, heating and power generation. It can be produced from a variety of available renewable resources, using several different methods of production such as steam reforming, partial oxidation, and electrolysis. Hydrogen can be stored, transmitted, and delivered to consumers using gas transport technologies that are similar to those for natural gas.

The introduction of a hydrogen fueling station and ultimately a hydrogen energy system will require that the technology be demonstrated as feasible and reasonable. The challenge lies in providing a clean and sustainable supply of hydrogen to the vehicle, whether it is reformed gasoline, methanol, natural gas or pure hydrogen. As Lovins and Williams (1999) state, "The key is not the fuel cell but rather how the fuel cell's best source of energy (hydrogen) will be manufactured, delivered, and stored"¹³ Any new hydrogen infrastructure introduced must be tested and accepted by industry, government, and consumers.

¹¹ Winter, Carl-Jochen and Joachim Nitsch. "Hydrogen as an Energy Carrier," pg.6. Today, this point is also reinforced through several comments by scientists and engineers through out the industry who claim that the method of production of hydrogen will be the key determinate on the acceptance of hydrogen as fuel. (See article by David Suzuki Foundation and the Pembina Institute).

¹² Winter, Carl-Jochen and Joachim Nitsch. "Hydrogen as an Energy Carrier," pg.6.

¹³ "Climate-Friendly Hydrogen Fuel: A Comparison of the Life-Cycle Greenhouse Gas Emissions for Selected Fuel Cell Vehicle Hydrogen Production Systems," The David Suzuki Foundation and The Pembina Institute, March 2000).

2.3 Hydrogen Availability and Cost

Another major issue arises from the uncertain prospects for general availability of hydrogen at competitive costs. This issue has been studied repeatedly with similar conclusions. A recent study by the Argonne National Laboratory¹⁴ developed detailed capital cost estimates for the production and distribution infrastructures for six fuels (RFG, diesel fuel, DME, methanol, ethanol, and hydrogen). Infrastructure costs were estimated for 2015 (limited penetration, requiring daily production and distribution of hydrogen with the energy equivalent of 70,000 barrels of gasoline) and 2030 (wide penetration; daily production of 1.6 million barrels of gasoline equivalent).

For hydrogen, the estimated production facilities capital costs were \$10 billion (2015) and 230-400 billion (2030); the costs of the required distribution facilities were \$7.7 and 175 billion. With the assumption that vehicles are driven an average of 14,000 miles/year at a fuel efficiency of 80 mpg (gasoline energy equivalent), the Panel estimates that these costs correspond to per-vehicle infrastructure costs of \$3,500 to 5,000; at a more likely 60 mpg, per-vehicle infrastructure costs are \$4,700 to \$6,700.

At a return of investment of 15%, the infrastructure investments alone would contribute between \$3.00 and \$4.30 to the cost of hydrogen with the energy equivalent of one gallon of gasoline; this would be appended by the costs of the precursor natural gas and of operating the production and distribution facilities.

Another recent study, performed by Directed Technologies, Inc.¹⁵, analyzed various hydrogen production schemes with capacities to serve between 5000 and 500,000 fuel cell vehicles and concluded that 5000 psi compressed hydrogen could be delivered to fuel cell vehicles at costs that would be competitive with gasoline per mile driven. The basis of this statement is a comparison of a gasoline vehicle operating at 24.5 mpg on taxed gasoline with a fuel cell vehicle achieving around 80 mpg (gasoline energy equivalent) on untaxed hydrogen. If the comparison were made between hydrogen and gasoline on the same basis (80 mpg, tax free), hydrogen would cost 2-3 times more per mile driven than gasoline even under most favorable assumptions.

¹⁴ K. Stork et al. "Assessment of Capital Requirements for Alternative Fuels Infrastructures," Argonne National Laboratory Report No. ANL/ESD/TM-140.

¹⁵ "Hydrogen Infrastructure Study Summary," Directed Technologies, Inc., Contract No. DE-AC02-94CE50389, July 1997.

The lowest estimate¹⁶ of capital costs for a large-scale hydrogen production and distribution infrastructure is \$100 billion for a system with one million barrels per day gasoline energy equivalent. At \$100,000 per barrel/day of capacity, Arthur D. Little's highly optimistic estimate is only one-third of the ANL number (\$405 to 575 billion for 1.6 million barrels/day, or about \$250,000 to 360,000 per barrel/day).

Even the lowest of the estimated investments needed for a general hydrogen supply infrastructure are unlikely to occur until the competitiveness of hydrogen with other automotive fuel cell fuels has become plausible and major prospective manufacturers of fuel cell electric vehicles have focused their development programs and product plans on hydrogen as the primary fuel.

Smaller, local or regional hydrogen supply infrastructures may present less of a barrier to investments. The current interest in smaller-scale hydrogen production and distribution systems is fostered by two developments: technically successful demonstrations of hydrogen-powered fuel cell buses, and the development of relatively small hydrogen generators derived from the steam reforming or partial oxidation-based fuel processors used for power generation or intended for automotive engine applications of fuel cells, respectively. Some developers (e.g., Ballard and Daimler Benz) believe that fuel cell buses could eventually become a fleet vehicle market for hydrogen that would be supplied by limited local or regional manufacturing and distribution facilities.¹⁷ Support for this belief comes from the developers of smaller-scale hydrogen production technology (e.g., IFC, ADL, Hydrogen Burner) and producers of industrial hydrogen (e.g. Air Products) who claim that cost of this hydrogen could be low enough for automotive applications. Namely \$2.50-3.00 per kg, or about \$2.25-2.75 (tax-free) per energy equivalent of one gallon of gasoline.

However, there is still considerable uncertainty regarding the capital cost of such units, and existing hydrogen fuel cost projections do not seem to take into account all the factors such as fail-safe compression, distribution, dispensing and storage of high-pressure hydrogen that will contribute to the cost of on-board hydrogen. Whether these issues can be satisfactorily resolved for fleet applications is presently unclear. It appears that local or regional populations of hydrogen-based fuel cell electric vehicles would be difficult to aggregate into the minimum market size (e.g., >100,000 units/year) needed to sustain mass manufacturing and achieve competitive costs of fuel cell-powered automobiles.

¹⁶ Presentation of Arthur D. Little at the Vice President's Automotive Technology Symposium No. 6, July 1997.

¹⁷ Tension between the incremental approach suggested by mid range strategy of fleets and regional fuels, and the persistent calls for a globally optimal approach.

In summary, difficult technical and cost issues surround the choice of hydrogen as the primary fuel for fuel cell-powered, mass-marketed automobiles. The present concentration of the major developers of automotive fuel cells on methanol and gasoline is a clear indication that they consider resolution of these issues in the near future to be less likely developing fuel cell engines that can use carbonaceous fuels of acceptable efficiency and cost (See Appendix 14 for further discussion of fuel cell vehicle developers).

2.4 Fuel Summary and Outlook

Methanol and gasoline are the current focus of worldwide efforts to develop automotive fuel cell engines. Hydrogen is likely to play a role in the foreseeable future in a limited volume produced from natural gas locally for bus or similar vehicle fleets. Better processability, somewhat higher fuel cell engine efficiency, reduced carbon dioxide emissions and longer-term energy advantages are claimed for methanol, but the fuel cycle consumes much more energy than does gasoline processing. The existence of the required production and distribution infrastructures is the obvious advantage of gasoline although it is not clear at present to what extent petroleum distillates need to be modified to meet the purity and processability requirements of “gasoline” fuel processors. The technical, economic and policy bases for a rational choice between methanol and gasoline are not likely to be available until current development efforts have proceeded considerably further and cooperative efforts between fuel cell engine developers and fuel suppliers have identified preferred fuel strategies for fuel cell electric engines and vehicles. These strategies may well turn out to be different for different regions.

Chapter 3: The Natural Gas-Hydrogen Transition: Fleet Application

3.1 From Natural Gas to Hydrogen

Hydrogen presents a unique opportunity to take advantage of the existing natural gas right-of-way. This will have an important impact on the introduction of hydrogen as fuel in the both the short and long-term. Although the costs associated with converting natural gas pipelines to hydrogen might initially be quite expensive, in the long run, a distributed network of Bi-fuel pipelines could dramatically reduce hydrogen's 'time to market'. When it is time to transition to hydrogen, a reformer can be attached at the end of the gas infrastructure. The hydrogen can then be run from the reformer to the fueling station, and finally to the bus. It would make for a short hydrogen link, which could perhaps be faster, cheaper and safer than other solutions. Natural gas thereby becomes an important element and provides for a very simple drop in change to hydrogen.

The technology and infrastructure required to produce, store, and distribute natural gas overlap significantly with those needed for hydrogen. Traditional natural gas pipelines could slowly transition to hydrogen, provided the necessary material and additional seals, compressors, and monitoring devices were included. The eventual transition from natural gas to hydrogen will require a minimal amount of material until replacement pipelines can be constructed specifically for hydrogen usage. For this reason, the present and expanded use of natural gas as a vehicle fuel could ease the entry of hydrogen into the U.S. energy market.

In theory, natural gas could be transported via pipeline in a blend containing up to 20 percent hydrogen, offering a cleaner fuel without modifying natural gas pipelines (the supply of natural gas could be reformed at the fueling station itself). However, modifying the same pipelines to carry pure hydrogen would require further research to address a number of differences between the two fuels. Similarly, the experience gained by transporters of liquefied natural gas would also be an asset as the market for shipping liquefied hydrogen grows.

The similarity between hydrogen and natural gas distribution via pipelines is significant for the implementation of a fueling station due to the need for low cost fuel availability, ease of transport through various methods, and use of existing infrastructure. The natural gas experience has shown that there are many connections between the systems to use natural gas and hydrogen in vehicles:

- The weight and volume of hydrogen fuel storage systems needed in fuel cell-powered vehicles are comparable with the weight and volume of the systems used successfully in natural gas vehicles.
- The materials and systems used to refuel natural gas vehicles are analogous to those used to refuel hydrogen-powered vehicles. For hydrogen-natural gas mixtures, they are the same as for natural gas.
- “Fast-fill” compressed-gas refueling technology can be adapted from natural gas systems and used to fill hydrogen fuel cell vehicles, offering a refueling time of about 5 minutes, which is comparable to gasoline refueling today.
- Natural gas and hydrogen both offer greater energy density in liquefied form than in gaseous form, reducing the space requirements of fuel storage by half, when compared with compressed gas.¹⁸

In all probability, natural gas/steam reforming method will remain the main method of hydrogen production during the next 10-20 years. Carbon emissions from the production of hydrogen from natural gas are similar to those for natural gas use in vehicles. Small-scale reforming of natural gas will be an important technology for the early demonstration and development of a hydrogen economy. Fleets of perhaps 50,000 to 100,000 fuel cell cars or 1000-2000 PEM fuel cell buses might be fueled without building new hydrogen capacity. Once demand for hydrogen exceeds this level, on-site production reforming or electrolysis could allow for additional hydrogen production capacity to slowly increase without building a new hydrogen pipeline system.

Long-term planning might encompass geographically concentrated demands allowing pipeline distribution to yield lower deliverable hydrogen costs. If hydrogen is made locally, when and where it is needed, it will avoid the costs of a national hydrogen pipeline system or a large fleet of liquid hydrogen tanker trucks. Ultimately, the hydrogen fuel cell economy and infrastructure would be better received in a small urban environment prior to a larger urban area (>250,000).¹⁹

Joan Ogden estimates that existing industrial hydrogen excess capacity in the LA basin could support 46,000 – 138,000 fuel cell cars or 700 – 2100 fuel cell buses.²⁰ Studies by DTI,

¹⁸ Canon, James. “Harnessing Hydrogen: The Key to Sustainable Transportation” New York: INFORM, 1995.

¹⁹ Hydrogen fuel cell vehicle demonstrations have used centrally fueled fleets in either a specific geographic area or a specific mile radius. Chicago and Vancouver demonstrations involved centrally fueled fuel cell buses traveling specific distances and daily routine schedules.

²⁰ Joan Ogden estimates that by the year 2020 there will be approximately 350,000 hydrogen fuel cell cars, 150,000 light trucks, and 330 buses. Hydrogen from existing sources will play a significant role in getting

Ford Motor Company, and US Department of Energy suggested that hydrogen could be produced economically on site at local gasoline stations or at fleet operator garages by either electrolysis of water or by steam reforming of natural gas. In effect, this scenario utilizes the existing natural gas infrastructure or the existing electrical power grid to provide energy to the station.

3.2 Fleet Use

One place where the set of issues about fuel cells may be sorted out is in bus fleets. Fuel cells may find an early application in bus fleets. Fleets utilize a centralized fueling station, which allow for the cost barriers to become less stringent. Centralized fueling stations for fleet applications are the first step in proving the infrastructure requirements associated with widespread introduction of a hydrogen powered transportation system. Hydrogen can be implemented first in centrally refueled fleet vehicles, and then gradually move into general automotive markets as both the availability of technology and as demand push the supply of hydrogen produced to more efficient economies of scale. In terms of costs per passenger, it is also cheaper to implement the new technology in a bus than in passenger vehicles.

Fleet managers are in an ideal position to consider using alternative fuels. Transport fleets often have refueling facilities on site, and the vehicles used in fleets travel a predictable number of miles per day. Fleet managers have control over the maintenance of their fleets and facilities. It would be difficult to justify a geographically widespread hydrogen fuel distribution system as general automotive use depends on widespread availability of fuel. Eventual implementation of this strategy would involve a societal consensus and commitment to move toward a zero emission transportation system.²¹

3.2.1 Fuel Cell Buses

The rationale behind using buses to demonstrate the feasibility of hydrogen as fuel is to develop the knowledge and expertise needed to introduce this technology given the current and future economic, infrastructure, sociological, and technological constraints. Specifically, the conceptual design for a hydrogen-powered fuel cell bus should consider the environment in which the bus operates. This includes the production and provision of hydrogen, storage and refueling, maintenance and repairs to the systems and buses, operating conditions and service

hydrogen fuel cell started over the next 5 –10 years. Ogden, Joan, “Developing an infrastructure for Hydrogen Vehicles: A Southern California Case Study”, *International Journal of Hydrogen Energy* 24 (1999) 709-730.

²¹ Commitment to adopt emission standards for transit buses were effective in 1996. See Appendix XIII

routes of the buses, and of the tank vehicles. The system could be designed in such a way as to permit the smooth integration of the new hydrogen technology in current operational procedures and services. Since the design of a hydrogen powered bus system is dependent on technical energy related and local conditions, successful implementation will require easily available and low cost hydrogen (cost may not be so important for a technology demonstration), proper equipment for on site hydrogen storage and fueling, and stringent regulation and of highly trained personnel for handling hydrogen.

If hydrogen is transported to the station in liquid form, it is logical that it should remain in that state for storage, bus refueling, and on-board use. Fuel in a gaseous state requires high-pressure storage at the depot and high-pressure or hydride storage tanks on the bus, the design and implementation of a hydrogen fueling station requires the operation of hydrogen powered buses to adapt to local conditions and to use a form of hydrogen storage suitable for the local conditions and technological design. Liquid hydrogen is commercially available in Los Angeles and the South Coast Basin, and can be easily transported to locations within the area with minimal new infrastructure.

Fleet demonstration of hydrogen as fuel will enable industry to decipher what needs to be changed, enhanced, or eliminated in the process to provide hydrogen to buses. It will also determine the gaps that must be filled before commercializing the technology for widespread fleet use. The bus concept enables fleet managers to develop training programs that are essential for the handling of hydrogen. The demonstration should reveal that without economic constraints, the benefits of hydrogen as fuel would be feasible in the longer-term. Given the right conditions, and considerable economic or governmental subsidy, fuel cell development could increase substantially in the short-run.

The bus concept utilizes liquid (or gas in some cases, NEBUS uses 21 kilograms of hydrogen gas pressurized to 300 bar, in seven glass fiber reinforced aluminum tanks) storage on the roof of the vehicle. Liquid storage offers the best results with respect to both weight and volume. A disadvantage of liquid storage is the daily evaporation rate (<1%). Storage in metal hydrides has been widely tested but is extremely unsuitable for buses because of increased weight. It is preferable to other storage systems if the hydrogen is already present in liquid form and no more energy is required for its conversion to the liquid state.

Buses would be refueled and serviced at a central location. Daily maintenance and safety checks would be performed. Provided that the suggested safety measures are observed, the use of

liquid hydrogen powered buses can be realized with no risk greater than that of existing diesel vehicles.²²

The relaxed method of fueling common to gasoline-powered vehicles can not be used when dealing with hydrogen. Special attention must be paid to the unique hazards of hydrogen. For example, static electricity can ignite hydrogen that leaks during refueling. Therefore, several changes in the current practice of conventional gasoline self-fueling must occur. A vehicle fueled with hydrogen must be electrically grounded prior to filling the tanks. A second concern of refueling is to prevent the vehicle from driving away while the refueling nozzle is still attached to the fuel port. Some of these problems have technical solutions, such as the use of electric interlocks - a switch is connected to the door of the fill port. Once the door is opened, a solenoid allows hydrogen to flow into the storage tanks. More importantly, the switch prevents the drive train from being activated, and therefore the vehicle can not be operated while the refueling nozzle is still connected to the fill port.²³

All components of the hydrogen production, distribution, and storage system must be carefully chosen with safety as the primary concern. Hydrogen detectors should be implemented in case hydrogen leaks from any components of the system (either on-board or at the refueling station). Purging of hydrogen is required when the vehicle is idle or shut down. When the vehicle is turned off, the purge solenoid is opened, releasing the hydrogen. Senior Research member of the MIT Energy Lab, Malcolm Weiss has posed the following vision of hydrogen use:

“If hydrogen is in widespread use in 2020, it will be manufactured by reforming natural gas at “service stations”. Other more expensive options include generating hydrogen at service stations by electrolysis of water, or reforming natural gas in large centralized facilities and piping compressed hydrogen or trucking liquid hydrogen, to services stations. In all cases, large new investments will be required for manufacturing, storing, and dispensing hydrogen.”²⁴

3.2.2 Vehicle Model and Requirements:

For the successful demonstration of a hydrogen-fueling station for fleet use, it is essential that the buses meet the following requirements:

- Standard scheduled service bus
- Original number of seats and standing room

²² EQHHPP Phase II Final Report, Section V-ii.9- “2.4 Safety Aspects for the LH2 Bus”.

²³ Ogburn, Michael, et al. “Systems Integration and Performance Issues in a Fuel Cell Hybrid Electric Vehicle,” Society of Automotive Engineers, Inc., publication 2000-01-0376, 2000.

- Storage tanks located on the roof
- Volume of the tank must be designed for a range between 250 to 350 kilometers
- Refueling either on side or overhead.
- Refueling can only be performed by *trained personnel*. It is essential that the pertinent regulations governing the *handling of hydrogen* is strictly observed and enforced.

In addition to the specific bus standards, several factors influence the success of whatever design is used for a hydrogen fueled bus including the *production* and provision of *hydrogen storage and refueling*, the *maintenance and repairs* to the systems and buses, and operating conditions, routes, etc.

Most transit agencies say that the clean air comes at a high cost. Natural gas powered buses (CNG) cost \$30-50K more than the standard diesel bus. Fuel cell buses have been priced at over a million dollars in demonstrations although, engine manufactures such as Ballard claim that this price tag will significantly decrease as the commercialization of fuel cell engines is realized.²⁵ Each transit agency has a different way of calculating other costs such as fuel, maintenance, facilities, and fleet scheduling. Los Angeles has the largest number of compressed natural gas buses (See Table 3.1). Lower costs and overall operational efficiency are a matter of management and commitment.²⁶

Table 3.1 Number of Alternative Fueling Stations in California and Los Angeles.

	M85	CNG	E85	LPG	ELEC	LNG	ALL
California	36	202	0	516	337	9	1100
Los Angeles	1	10	0	20	25	2	58

* As of April 2000 (Adopted from NREL Alternative Fuels Home Page – www.afdc.nrel.gov)

Transit agencies attempting to introduce alternative fueled buses should expect to encounter difficulties and confront problems as they arise. The commitment to making the change is the biggest hurdle to overcome. Operating and maintenance costs of alternative fueled buses (such as CNG) have traditionally been associated with the ability of the transit agency and fleet manager to manage their facilities and buses efficiently and effectively. The older the bus is the more it costs to maintain.

²⁴ Malcolm Weiss, MIT Energy Lab – Correspondence January 2000.

²⁵ Fuel cell engine commercialization could occur as early as 2003.

²⁶ Bill Clapper – Interview March 2000.

Fleet managers are looking at acquiring alternative fuels and vehicles as part of the requirements of the Energy Policy Act of 1992. The Act applies to federal, state and fuel provider fleets located in certain geographical areas to replace older buses with alternative fueled vehicles. These geographical areas are metropolitan statistical areas or consolidated metro areas, as established by the Bureau of Census, with a 1980 population of more than 250,000 people.

Fleet managers in California also face state regulatory requirements that require a reduction in average fleet emissions. On February 24, 2000, the California Air Resources Board adopted regulation that will further reduce air pollution from the state's transit buses and require some fleet operators to start using Zero Emission Buses (ZEB) in three years. The regulation, which will begin to be phased in 2002, will affect about 8,500 buses at approximately 75 California transit agencies. The proposed bus fleet requirements (Table 3.2) are designed with the intent to bring quick, near-term emissions reductions and long-term, near-zero emission benefits.

Table: 3.2 Urban Transit Bus Fleet Rule Requirements and Emission Standards

Proposed Urban Transit Bus Fleet Rule Requirements and Emission Standards				
Model Year	ADiesel Path		Aalternative-Fuel Path	
	NOx (g/bhp-hr)	PM (g/bhp-hr)	NOx (g/bhp-hr)	PM (g/bhp-hr)
2000	4.0	0.05	2.5 optional ₍₁₎	0.05
10/2002	2.5 NOx + NMHC	0.01	1.8 NOx +NHMC optional ₍₁₎	0.03
7/2002	Low Sulfur Diesel Fuel		Low Sulfur Diesel Fuel	
10/2002	4.8 NOx fleet average		4.8 NOx fleet average	
2003-07	PM retrofit requirements		PM retrofit requirements	
7/2003	3 bus demo of ZEB's for large fleets (>200)			
2004	0.05	0.01		
	Or greater emission benefits			
2007	0.2	0.01	0.2	0.01
2008	15% of new purchases are ZEB's for large fleets (>200)			
2010	15% of new purchases are ZEB's for large fleets (>200)			

Source: ARB Cuts Emissions from Transit Buses, Press Release 00-03, February 24, 2000.

Notes: Shaded area shows existing requirements and existing optional emission standards.

(1) Although transit agencies on the alternative-fuel path are not required to purchase engines certified to these optional standards, the staff expects that they will do so in order to qualify for incentive funding. At present the only alternative-fuel engines available are certified to optional, lower-emission NOx standards.

This will create an aggregate demand for hydrogen of about two million standard cubic feet per day by 2010. One million scf/day would fuel 80 fuel cell buses per day. There are three

general strategies currently available for producing, distributing and storing hydrogen in such quantities:

- Hydrogen can be produced at *large centralized facilities* and *distributed* via pipelines or trucks to refueling stations. This strategy is similar to the current refinery and gasoline infrastructure.
- Hydrogen can be produced at a larger number of *smaller decentralized facilities*. The hydrogen could be *produced and delivered* to the vehicle at the filling station.
- Fuel processors can be used to *convert traditional fuels*, such as gasoline, methanol, ethanol and methane, into hydrogen directly *on board* the vehicle. This option would make use of readily available fuels and existing infrastructure.

All options present technical challenges as well as environmental, economic, and societal costs and benefits. The final decision for production, distribution, and storage will ultimately lie in the hands of the fleet manager to compare the costs and benefits of each different technology. The methods of production and/or delivery of hydrogen to the fuel cell bus will determine the design requirements of a hydrogen fueling station.

3.2.3 Delivering Fuel to the Fuel Cell

Innovation over the last several decades regarding transportation fuels has allowed the automotive industry to develop and slowly transition to cleaner fuels and shift to renewable fuel sources that were previously unattainable. These discoveries and technological achievements have enabled a reevaluation of current forms of energy supply and allow the appropriate means to achieve a more a sustainable form of energy to be determined. The design and introduction of a new energy system will require fleet managers to consider the appropriate method of delivering fuel to the fuel cell. The different methods of hydrogen delivery are detailed below.

Truck Delivery: Liquid hydrogen costs \$20-30/GJ depending on station size. Best solution for immediate demonstration. For centralized hydrogen production systems, it is assumed that hydrogen is transported to fueling stations by truck. Once hydrogen fuel demonstrates demand and the need for increased supply, other alternative methods of production, distribution and storage will become more acceptable to fleet managers.

On Site Reforming: Natural gas can be reformed on site in an economically attractive manner with the added benefit that no distribution system is required. This is initially expensive

at small station size but financially viable for larger stations. This is currently the most widely used, cost effective and efficient hydrogen production process. The process involves the catalytic conversion of methane and water at high temperatures (769-925°C) to produce carbon dioxide and hydrogen. A large-scale reforming plant might achieve fuel conversion efficiencies of 83%.²⁷

Pipeline Delivery: Natural gas and crude oil could be pipelined from processing facilities to reforming plants. Hydrogen could also be produced at an off-site reforming facility and piped to fueling stations via hydrogen pipelines. The capital costs of building a small hydrogen pipeline would be \$1 million/mile in the heavily populated area of Los Angeles. The leveled cost of pipeline delivery in Los Angeles is approximately:

$$\frac{\text{Pipeline (\$/GJ)} = \$1.2/\text{GJ} \times \text{distance (in km)}}{\text{Flowrate (in millions scf H}_2\text{/day)}}$$

Centrally Produced Hydrogen: \$3/GJ Refinery excess

\$5-9/GJ Large scale steam reforming

\$8-10/GJ Biomass, coal, or municipal solid wastes.

For a system of small-scale hydrogen pipelines to be economically competitive a large demand would be required. Because of the high cost of building small scale gaseous pipelines, the development of a new large scale, centralized production facility with pipeline distribution would require a large, localized hydrogen demand. According to Joan Ogden (1997), “The capital costs of building a hydrogen refueling infrastructure is often cited as being a serious impediment to the use of hydrogen in vehicles”.

Process Gasoline and Methanol On Board Fuel Cell Vehicle

Reform gasoline, methanol, ethanol, or natural gas into hydrogen. Hydrogen is then delivered to the fuel cell. A multi-fuel processor will operate on the heat recovered from the fuel cell to continually deliver hydrogen to the fuel cell.

²⁷ “Climate-Friendly Hydrogen Fuel: A Comparison of Life-Cycle Greenhouse Gas Emissions for Selected Fuel Cell Vehicle Hydrogen Production Systems,” The David Suzuki Foundation and The Pembina Institute, March 2000.

On-board Storage

This process involves storing hydrogen on board vehicles in tanks similar to gasoline tanks. Compressed hydrogen tanks offer rapid refueling capacity, little fugitive emissions, minimal infrastructure costs, high safety due to the inherent strength of the pressure vessel, and simplicity of design. Ambient temperature compressed gas storage as opposed to liquefied hydrogen storage is considered the most appropriate fuel storage system. According to Ballard, a 600-km range vehicle will require 4.7 kg of hydrogen.

Chapter 4: The SunLine Transit Agency Experience

4.1 Los Angeles, California

California is the world's seventh largest economy and continues to grow both in economy and in population. The population boom has caused mobility and transportation in California to become increasingly reliant upon passenger vehicles. Today, California is host to the most cars per capita in the world, over 26 million vehicles. It is no wonder that Los Angeles has been designated as 'extreme' by the National Air Quality Standards. The need to address the issues of mobility, population growth, and clean air in all areas of California has received attention since the adoption of the Clean Air Act in 1970. The introduction of strict standards for vehicle emissions have proven that clean air programs work – a new 1999 California vehicle is 95% cleaner than a new vehicle in the early 1970's. However, this is still not enough to change the effects of the growing number of vehicle emissions and deterioration of the environment.

The Los Angeles region, with a population of some 16 million, is among the most intensively automobilized urban area in the world; its air is among the most polluted. More than 70% of the pollution is transportation related. Air pollutants of special concerns are carbon monoxide, particulates, and ozone. Ambient ozone levels are typically two to three times higher than the national standard. The Los Angeles South Coast Air Basin has long held the dubious distinction of having the worst air pollution problem in the nation and is the only part of the US that has been given a classification by the EPA of 'extreme containment' with respect to air quality requirements. According to the South Coast Air Quality Management District (SCAQMD), on-road mobile sources were responsible for a staggering two-thirds of total emissions in the Basin (SCAQMD 1987).

Transportation is an essential contributing factor to the quality of life in Los Angeles. Transportation facilities and policies are integral elements in achieving sustainable transportation objectives. Transportation encompasses a major part of the economy through a complex combination of three very large components systems – infrastructure, vehicles, and energy. Today, all three systems are under tremendous stress. If all three factors are not considered when developing alternatives, the eventual outcome will be extremely desegregated, and very expensive to fix.

A comprehensive strategy of physical and operational improvements, and behavioral changes that reduce the length and number of trips generated is necessary to ensure future mobility in the city. The transportation system of the future will need to be a fully integrated, multi-modal system that offers multiple choices to Los Angeles travelers. Innovations in transit

service have already begun to augment the city wide bus system, one of the largest transit systems in North America. New technologies, such as alternative fuels, are beginning to have a significant impact on the environment and transportation system as a whole. LADOT currently operates the second largest transit fleet in Los Angeles County next to the LA County Metropolitan Transportation Authority (LACMTA). LADOT's fleet consists of almost 400 vehicles and is committed to developing and operating clean fuel vehicles such as compressed natural gas (CNG), propane, electric, and hybrids. California and its commitment to illustrating the potential use of alternative fuels for vehicles is extremely significant to the development of short-term and long-term strategies for implementing hydrogen as fuel. Past and present experiments, demonstration, and commitment to the development of programs to facilitate the transition to alternative fuels is crucial to the successful development of a hydrogen fueling station in Los Angeles. Los Angeles has demonstrated a commitment to transition to alternative fuels. This demonstration hopes to achieve political, social, and financial success that can create an awareness that environmental initiatives can work, and can act as a catalyst to other states to develop programs of their own.

The city of Los Angeles is facing the challenge of providing appropriate transportation for its 3.5 million residents while complying with stringent air quality standards and vehicle emission regulations. Using population forecasts, Los Angeles is preparing a strategic plan that will embrace methods of transportation to meet the population demands, while enhancing rather than degrading the environment. After many years, Los Angeles residents have had to settle for policy measures that are designed not necessarily to improve air quality, but to prevent it from becoming worse. The only way pollution levels in Los Angeles would be significantly curtailed would be to provide a major overhaul of the industrial and transportation structure, place severe limits on growth, and introduce a radical change in life-style.

Between 1998 and 2005, the population of California will grow by 4.8 million residents to nearly 37.8. California is growing faster than the national average (12.% compared with 5.9% , See Table in section 2.1.1).

Table 4.1.1 Expected Population Growth in the Los Angeles Area 1994 to 2020.

	1994	1998	2020
Los Angeles	9,231,600	9,603,300	12,249,300

Source: City of Los Angeles General Plan – Transportation (www.afdc.nrel.gov)

The effects of transportation on the environment have severely impacted air quality, specifically in southern California. Although enormous progress has been made in reducing emissions from motor vehicles during the last 25 years, and new standards have been adopted to further reduce emissions, vehicles still contribute significantly to air pollution. An important objective may not be to get the individual to give up their car, but to drive less or possibly give up their second car. Economists maintain that a high price for automotive travel will cause motorists to voluntarily decrease car use. The freeway is already in place, the problem is make the most effective use of it. Perhaps the most appropriate strategy for Los Angeles would be to forego the marginal strategies of accommodating regulation with societal needs. The more radical approach of raising the cost of freeway travel (through the use of tolls and taxes) could generate the funds required to secure a more effective transportation system (public transit, light rail). Los Angeles is currently making improvements to shuttle service in the downtown area (DASH system) and expanding their light rail system, while simultaneously experimenting with alternative fuel vehicles to persuade society to commit to cleaner transportation.

The strong commitment to environmental quality in California and the presence of powerful air quality regulators, suggest that alternative fuel vehicles are likely to gain some share of the Californian market in the future²⁸. California voluntarily adopted strict emission standards in an attempt to reduce mobile sources of pollution. In continuing California's commitment to reducing air emissions from vehicles, strong government initiatives to support plausible alternative fuels during 2000-2005 include:

- Modified fuel efficiency standards that encourage manufacturers to market alternative fuel vehicles.
- Requirements that urban-based fleet operators convert to alternative fuel vehicles.
- Lower vehicle emission standards that may be more easily met by non-petroleum fuels.

During the transition period, the difficulty and cost of establishing a network of retail outlets serving alternative fuels will result in using multi-fuel vehicles.

Los Angeles and other parts of California have developed dispersed land use patterns that have increased reliance on automobile travel. As the population dispersed and increasingly fewer people worked downtown, transit systems deteriorated. Residents of Los Angeles have had a love affair with the automobile. They claim that an automobile provides comfort, privacy, music, and

²⁸ As mentioned earlier, Joan Ogden estimates (1999) that by the year 2020 there could be 350,000 hydrogen fuel cell cars, 150,000 light trucks, and 330 buses.

freedom. Buses on the other hand, have a serious image problem. What incentives would attract individual riders to a smelly old bus? There is widespread concern about the quality of the bus system and that automobiles are the only method of transportation to provide the best travel time, cost, and service reliability.

If Los Angeles remains committed to the automobile as the main source of travel, then the answer is to make the car cleaner. The demonstration of buses that transition to hydrogen fuel will not only provide an alternative to the car as a 'cleaner' source of transit, but also enable industry manufacturers and energy suppliers to gain insight into the requirements needed to design and develop an infrastructure to support hydrogen fuel cell cars.

The role that improvements in vehicle design and emissions control will play in improving the image of the bus may further increase its acceptance as a mode of transport. A vast system of public transit must be created in Los Angeles to address growth, air quality, and transportation. In addition to alternative fuels, major impacts on air emissions will ultimately require strategic planning efforts for a comprehensive transit program. The introduction of a public transit program using alternative fuel buses in Los Angeles should also aim to:

- Reduce freeway congestion
- Reduce periods of congestion (ie. Traffic)
- Provide new levels of mobility (within urban areas and for commuters)
- Provide access to those who do not or cannot travel by automobile.
- Acquaint people with the many beneficial attributes of hydrogen powered vehicles.

The city has shifted its approach to resolving transportation and air quality problems by linking population and employment concentrations with transit systems. The on-going development of an extensive regional transit system present the opportunity of moving towards the goals of less dependence on the automobile and cleaner air.²⁹

²⁹ The reasons for the downward trend in public transportation include continued migration of jobs to the suburbs, declining role of central cities as a destination; dispersal of employment and housing within metropolitan areas, with suburb to suburb travel becoming the dominant commute patten; changing work patterns that involve less regularity in commuting; and the complex routing needs of two-worker households that require multiple stops along the commute route ("trip chaining") and make the use of transit time-consuming and inconvenient. These demographic trends are expected to continue exercising a dampening effect on the use of public transit in North America, especially in medium size and small urban areas. Although similar trends are in evidence in other parts of the world, they are likely to have a lesser impact on transit usage in the cities of Europe, Asia and South America because of greater willingness by authorities to invest in new transit infrastructure, more aggressive efforts to improve transit service and a less accommodating public policy towards cars in the cities.

The Metro Transportation Authority (MTA) is the major transit operator in Los Angeles with approximately 200 bus routes of all types. As one of the largest transit operators, the MTA currently relies on the internal combustion engine for public transportation. Approximately 50 routes in the MTA system are express or hybrid local-express routes connecting the regional travel markets to the urban core. The Los Angeles Department of Transportation (LADOT) also operates 8 commuter express lines as well as the Downtown Area Short Hop (DASH) system. The MTA has a large stake in the development of alternatives to the combustion engine as the capital costs of switching to hydrogen (or another similar alternative fuel) would be substantial. However, Los Angeles recognized an opportunity to experiment with alternative fuels through purchasing alternative fuel buses and placing them into short route service. The several express routes and shuttle services that MTA operates is an ideal fit for demonstrating the feasibility and practicality of alternative fuels. The DASH system uses a number of alternative fuel vehicles in its fleet, including CNG, LNG, Propane, and Electric. On a daily basis 4.6% of all person trips in the city are taken on transit buses, while the rest of the region's transit by bus is just over 1%.³⁰

Can the City of Los Angeles Support a System of Hydrogen Fuel Cell Buses?

Los Angeles represents a unique opportunity for both the demonstration and the ultimate implementation of a hydrogen fueling station. LAMTA has experimented with a variety of alternative fueled vehicles since 1989 and is now the home of the nations largest alternative fuel fleet (MTA's fleet is expected to be more than 50 percent alternative fueled by the end of 2000). The bus fleet in Los Angeles is expected to grow from 2976 buses (1996) to approximately 3300 buses by 2010.³¹ The focus of MTA has been to develop a vehicle that would have sufficient power to meet the demanding driving requirements of Los Angeles and satisfying MTA operators.

A number of transit agencies have experimented and are operating fleets of alternative fuel buses. The transition from conventional gasoline fuel buses to alternative fuel buses has been somewhat difficult. The difficulties arise in the absence of adequate guidelines to address the issues involved in the design of the facilities and vehicles to ensure a safe and smooth transition. However, fuel cell technology has been demonstrated to be feasible for fleet use (See Chicago Transit Authority) and hydrogen in Southern California is currently available from two industrial gas companies - Praxair Inc., and Air Products and Chemicals Inc. There is ample natural gas

³⁰ LA City General Plan – Transportation, <http://www.cityofla.org/PLN/Trans-Element/TE/ch2.htm>

³¹ Ogden, Joan. "Developing an infrastructure for hydrogen vehicles: a Southern California Case Study," *International Journal of Hydrogen Energy* 24 (1999) 709-730.

resources available in the Los Angeles area and industrial gas suppliers have indicated that they could build a new, large hydrogen plant based on steam reforming of natural gas in 2-3 years (with output capacity of 25-100 million scf/day).

According to Joan Ogden, the two main industrial gas companies (as noted above) have the ability to supply hydrogen in Southern California. "Praxair has a hydrogen plant in Ontario, California which currently produces 15 tons/day of liquid hydrogen for users in the aerospace industry and to chemical industries. Although most of the current output of the plant is already committed, there may be a million scf/day or so available for transportation fuel. The price of liquid hydrogen in Los Angeles area at demand levels 0.1-2.0 million scf/day is currently about \$1.1-1.5/lb or \$17/GJ. Air Products and Chemicals also have a new 80-million scf/day hydrogen plant in Wilmington, California to provide gaseous hydrogen to near by oil refineries. The cost at a large reformer might be \$5-9/GJ. Ogden estimates that the cost of pipeline delivered hydrogen transportation fuel could be as low as \$12/GJ for a demand near a low cost supply."³²

"As we went around the table one by one, the overall consensus was that the fuel suppliers - indicating that they would require a purchase order and some time - would provide the fuel. There is no problem! And it suddenly came to the realisation of everyone there that this is doable with present technology. Bring in the cars. Issue purchase orders. You will have the fuel. And that came as a bit of a surprise to some of the people there from the government."³³

The daily demand of hydrogen for a bus depot in Los Angeles could be large enough to bring the delivered cost of hydrogen down somewhat because of economies of scale, especially for stations based on small-scale reformers. All urban transit bus depots in the Los Angeles area are within an hour or so of the Praxair liquid hydrogen plant. Several bus depots are located in the Long Beach area, possibly within short, local pipeline distance of refineries of the Air Products plant. Alternatively, on site production of hydrogen from natural gas might be used. Rapid developments in small-scale reformer technology are making this an increasingly attractive supply option. Southern California's Gas Distribution System carries about 3 billion scf of natural gas per day.³⁴ Fuel cells might have the opportunity to be economically competitive first in bus

³² Ogden, Joan. "Developing an infrastructure for hydrogen vehicles: a Southern California Case Study," *International Journal of Hydrogen Energy* 24 (1999) 709-730.

³³ California Fuel Cell Partnership meeting, comments from Dr. Paul Scott (National Hydrogen Association) representing Stuart Energy Systems.

³⁴ Ogden, Joan. "Developing an infrastructure for hydrogen vehicles: a Southern California Case Study," *International Journal of Hydrogen Energy* 24 (1999) 709-730. The cost of liquid hydrogen in Los Angeles area at demand levels of 0.1-2.0 million scf/day is \$1.1-1.5/lb or \$17-23/GJ. A liquid hydrogen refueling station might add several \$/GJ to this cost. Fueling a fleet of 200,000 FC vehicles and light trucks plus 330 buses would require 26 million scf/day of hydrogen.

markets, where cost goals are not as stringent as for automobiles. As technologies develop to reduce hydrogen production costs and delivered costs, hydrogen fuel cell buses will become increasingly attractive to fleet managers in Los Angeles.

4.2 Technology and Fleet Demonstration

SunLine Transit Agency, Coachella Valley, California	
Population	260,000
Area	406 m2
Rider-ship	3,500,000
Annual Operating Budget	\$11,000,000
Distance each year per CNG Bus	43,000 miles
Fueling Station Cost (development & construction)	\$1.47 million
Size of Fueling Station	1200 scfm with 2 compressors.

The SunLine Transit Agency, who operates a fleet of 50 alternative-fueled buses in the Palm Springs area of southern California, is considered a ‘trail-blazer’ in the development of alternative fueled fleets. The SunLine Transit Agency ‘jumped with both feet’ into using a new technology, spurring product advancement, and paving the way for other systems (such as hydrogen). SunLine decided to switch its aging diesel fleet with alternative fuel vehicles. To make it feasible, SunLine decided to replace its entire fleet with compressed natural gas vehicles. The new fleet was delivered and placed into service in May 1994.

“The transition to compressed natural gas from diesel required new training regarding how to work with high pressure systems, new types of refueling infrastructure, working with valves structures and large stationary compressors. One has to deal with "pull-aways" where someone inadvertently forgets to unhook the hose after the refueling is complete and drives off with the hose. There are more diagnostics involved with compressed natural gas than diesel and we expect the same with hydrogen but our mechanics have a higher level of training. In fact when we go out for new hires we look for automobile mechanics because they have more diagnostic training than diesel mechanic”.³⁵

³⁵ Bill Clappers, SunLine Transit Agency (Correspondence February 2000)

The success was immediate: ridership increased and operating costs declined (the costly components of the demonstration were the compressor and the storage systems). SunLine’s decision to use compressed natural gas was more than just a fleet conversion. Through partnerships with local governments, businesses, and local community college, SunLine has advanced the knowledge and use of alternative fuel vehicles for California and the nation. The change represented an opportunity to establish the infrastructure for further experimentation with alternative fuels and would allow the entire region to convert to clean air fuel. Public and private partnerships allowed SunLine to work with the local college to establish a training program on the use of alternative fuels. Individuals can now become natural gas (or alternative fuels) certified - a sure requirement for the future hydrogen station.

<i>The SunLine Experience</i>	
Willingness	<ul style="list-style-type: none"> • Visionary board of directors who wanted to look at alternative fuels as an option.
Opportunity	<ul style="list-style-type: none"> • A desperate need to replace an aging diesel fleet. • Identified funding partners who could help meet the Board’s aggressive objective. • Interested in promoting natural gas vehicles, SoCal Gas offered SunLine a proven technology and funding for a \$1.5 CNG fueling station. • In working with SoCal Gas, the Board recognized that this could be more than a fleet conversion and was a window of opportunity to establish an infrastructure for clean fuel. • Worked with nine member cities to secure unanimous commitments to convert their municipal fleets to CNG.
Capability	<ul style="list-style-type: none"> • Skill and knowledge of the options available. Opportunity to take a leadership role in a proven technology that is ready today. • Teamed with College of the Desert (a local community college) to establish a CNG training program for mechanics. The program was then replicated at seven colleges throughout California.

SunLine's advocacy of and participation in alternate fuels projects has brought millions of dollars into the Coachella Valley. Since rolling into service in 1977, SunLine Transit Agency has

grown from a 22-bus service carrying 500,000 passengers per year to a 50-bus fleet carrying almost four million passengers annually.

According to SunLine's executive director, Bill Clappers, they expect the learning curve from the bus demonstration to bring the purchase price of a fuel cell bus into the \$600,000 range by 2008 vs. a \$330,000 CNG bus as of today. Today's CNG buses have "flatlined" in price, which is a function of availability and acceptance of the new buses and is also related to the introduction of the fuel cell. The fuel cell will achieve lower cost when lower cost materials replace such materials as platinum.

Notable for their interest in advancing alternative-fueled buses, transit agencies were invited to serve as test sites for the first phase of the Partnership's bus demonstration program. It is not the politicians that have to be convinced about the importance of developing and demonstrating hydrogen fuel cell technology. It is the fleet (trucking and bus) industries that must be convinced as well as the General Managers, Directors, Managers, Supervisors, Mechanics, and Operators. They are the individuals who at the end of the day are responsible for the social and financial bottom line. Bill Clappers believes that these individuals are the people who will make things work. "If they do not believe and do not try to make it work - it won't work". If fleet managers are not convinced of the benefits of conversion, or are not even motivated to look at the impact of an eventual conversion in the future, then the length of time for hydrogen technology to become dispersed into society will increase.

Resistance by fleet managers to visualize hydrogen as the energy carrier of the future may be due to the lack of infrastructure to support their operations. Changes will occur if a demonstration of alternative fuels such as hydrogen is feasible in fleet application. Change is definitely inevitable as stricter air emissions standards and regulatory pressures on industry increase. Fleet managers feel the pressure of compliance, but for the most part are wary of the procedures and cost required in doing so. Automotive manufacturers are already positioning themselves for the future, as are the energy providers³⁶. They do not wish to be left with "stranded" capital.

As part of that effort, next year each agency will acquire two fuel cell-powered buses and include them in regular revenue service on scheduled routes throughout their service areas. The learning from the SunLine demonstration will be directly transferable to other states (such as Massachusetts). SunLine is under agreement with a sister transit property in San Diego to transfer

³⁶ Traditional oil providers are slowly transitioning to become "energy providers", such as Shell Oil's transition to 'Shell Energy'.

SunLine's technology base to them over the next three years. At the same time, the California Fuel Cell Partnership plans to deploy up to twenty fuel cell-powered buses by 2003.

If there was one barrier to implementation of a hydrogen station other than cost, what would you say it is?

“Willingness to take a chance on new technology and new approaches to transportation. Progressive thinking”.

--- Bill Clappers, SunLine Transit Agency (Correspondence, February 2000)

Los Angeles is stricken with environmental degradation from various pollutants. The primary reason Los Angeles is the focus of attention for a majority of air quality improvement programs is because of mobile sources of pollution (See Appendix 2 & 3). Transportation accounts for almost two-thirds of the regions air pollution. Los Angeles has gained so much attention is the state and federal recognition of the 'extreme' air quality of the area. National Air Quality Standards have been established and Los Angeles is the only state designated as 'extreme'.

The transportation system that has evolved in California has allowed Los Angeles to become a viable test-bed for alternative buses. Although the area is unique in nature and design, its components share similarities to cities throughout North America. Finally, the last important criteria for choosing Los Angeles as the primary focus for implementation, is the warm reception of regulatory agencies to look at opportunities and alternatives to air pollution. The current culture is open to implementing effective strategies and solutions for cleaning the air in California.

Chapter 5: Hydrogen Energy System Infrastructure Requirements

5.1 Issues and Options

“Is a hydrogen economy a fantasy, bold vision, or inevitable outcome?”³⁷

Although hydrogen has been proclaimed as the energy carrier of the future, it is likely to be confronted by many obstacles before it is widely accepted. It will probably experience significant hurdles during its introduction as well as persistent push-pull demand on individuals to take the necessary steps toward achieving and supporting the new alternative fuel infrastructure. All of the components of this new energy carrier must provide higher efficiencies, lower production costs and higher per unit performances. The creation and management of a hydrogen fuel system will require extensive commitment and investment by industry, government, and society. To date, the infrastructure for hydrogen is non-existent due to heavy economic barriers. Retail fueling station storage, dispensing, and distribution also remains the biggest barriers for this system of energy. To determine the necessary actions required to implement hydrogen as the energy system of the future, the political, social, and regulatory issues must also be addressed in order to assign responsibility, action, and commercialization of a hydrogen fueling system.

To commercialize hydrogen as a transportation fuel each of the following are necessary: from renewable sources such as solar, wind, and biomass energy; to design, build and operate a refueling infrastructure; to operate and maintain hydrogen fueled vehicles; to deliver training and support services to sustain the cluster of hydrogen vehicles; and, to convert development projects into commercial applications.³⁸

Although hydrogen is the earth’s most abundant element, production, distribution and storage of enough hydrogen to supply a fueling infrastructure in the United States has yet to be realized. Hydrogen production in 1993 the United States alone was over 5 billion cubic meters (178 billion cubic feet). Most of the output is consumed in ammonia production and in the stripping of sulfur from petroleum during the refinery process. Hydrogen can be produced from various sources and through different methods of production. Industry produces hydrogen for a variety of purposes. More than 99% of the hydrogen produced world wide comes from fossil fuels. Virtually all hydrogen is produced in the chemical industry as a feedstock, while NASA uses a small portion as fuel.³⁹ The eventual implementation of a hydrogen fueling station and its associated infrastructure requirements will ultimately require an adequate supply and system of

³⁷ Winter, Carl-Jochen and Joachim Nitsch. “Hydrogen as an Energy Carrier,” pg. 5.

³⁸ “Hydrogen Program 1999 Annual Operating Plan”, Prepared for the U.S. Department of Energy by Energetics Inc. December 1998.

hydrogen energy similar to the existing infrastructure for gasoline. The various methods of production, distribution and storage are detailed below.

5.2 Production

To be considered pollution-free, hydrogen must be derived from renewable energy source such as solar, wind, and to some extent, biomass. Unfortunately, hydrogen from these sources is not yet available at a commercial scale. Improved processes and production methods that utilize renewable energies will require the existence of a supporting network of consumers utilizing hydrogen energy.

“Fuel cells will provide a major environmental step forward only if we chose the cleanest methods to manufacture and deliver hydrogen. If the right decisions are not made, this revolutionary technology will perform only marginally more efficiently than current engines, we will simply shift much of the pollution from the tail pipe to hydrogen production plants, and our vehicles will continue to contribute to global warming.”⁴⁰

Most of the hydrogen produced today is made from natural gas in a process known as steam reforming. Although natural gas is a fossil fuel source with carbon emissions, it is currently the cheapest and most firmly established method of producing hydrogen and will serve as the dominant method of production until technologies based on renewable energy resources become commercially competitive. All methods of producing hydrogen from renewable resources face technical and economic barriers that must be overcome if hydrogen is to fuel a sustainable transportation economy.

In terms of the entire energy chain – from production of the fuel to its consumption in the vehicle – far lower levels of greenhouse gases are generated than is the case with conventional automobiles. According to the Vancouver-based David Suzuki Foundation and the Pembina Institute of Drayton Valley, Alberta, the way that hydrogen is produced will have a significant impact on the fuel cell’s success as a greenhouse gas fighter.⁴¹ The report concludes that setting up reformation plants to produce hydrogen from natural gas was the most efficient method. The study suggests that large-scale reformation plants were slightly more efficient than smaller-

³⁹ Canon, James. “Harnessing Hydrogen: The Key to Sustainable Transportation” INFORM, New York, 1995.

⁴⁰ Hart, David. “Fuel Cells – A Green Solution?” Report written by the Pembina Institution and the David Suzuki Foundation, March 2000.

⁴¹Hart, David. “Fuel Cells – A Green Solution?” Report written by the Pembina Institution and the David Suzuki Foundation, March 2000.

volume plants. Small-scale plants have a practical advantage because they could be set up at service or fueling stations using the existing natural gas distribution pipeline system.

5.3 Distribution

The vast majority of hydrogen produced today is transmitted only a short distance before use (via pipeline, similar to natural gas). Long distance distribution is primarily in liquefied form in large tanks. Techniques for central bulk storage are also important for the distribution infrastructure. There are over 10,000 bulk shipments of liquid hydrogen per year in the US to over 300 locations, with NASA as the largest customer. Hydrogen pipeline systems are very small totaling only about 450 miles.⁴² Air Products and Chemicals, Inc., has two gaseous hydrogen pipelines in the US, one near Houston, Texas, and one in Louisiana. The total length is, approximately 110 miles and on average, carries 190,000 kg/day.⁴³ If hydrogen pipelines were to be expanded, possible embrittlement problems would have to be considered. Some steel and welds could be compatible but others might be subject to embrittlement, particularly with older pipes and welding. Hydrogen pipeline distribution is a firmly established technology, although a key obstacle with fuel availability is the scale of expansion needed to serve transportation markets. The Department of Transportation safety standards for hydrogen and natural gas pipelines are currently the same.⁴⁴

5.4 Storage and Transportation

Fuel storage is perhaps the greatest technical challenge affecting hydrogen's future as a transport fuel. Special storage and dispensing systems are required.

Storing hydrogen on board a vehicle raises three critical issues: the weight of the fuel storage system, the system's volume, and the speed or ease of refueling the vehicle. These limitations can be minimized if hydrogen is used in fuel cells, because fuel cells' inherently high efficiency reduces the amount of fuel a vehicle must carry. In contrast, the greater amount of fuel needed to power a hydrogen internal combustion engine vehicle makes these vehicles somewhat less practical.⁴⁵

⁴² Canon, James. "Harnessing Hydrogen: The Key to Sustainable Transportation," New York: INFORM, 1995.

⁴³ Daniel Morgan. "Hydrogen as Fuel" Congressional Research Service Report for Congress, 93-350 SPR, p.8, March 22, 1993

⁴⁴ Morgan, Daniel and Fred Sissine. Congressional Research Service Report for Congress "Hydrogen: Technology and Policy" 95-540 SPR, April 28, 1995.

⁴⁵ Canon, James. "Harnessing Hydrogen: The Key to Sustainable Transportation," New York: INFORM, 1995.

Since hydrogen is one of the lightest elements and has very small molecules, it can escape from tanks and pipes more easily than conventional fuels. However, if it is to be used as a fuel for transport or power generation there must be ways of storing hydrogen cost-effectively as well as transporting it from the place it was generated to the place where it is used. Storing hydrogen can be done in three main ways: in compressed form, liquid form and by chemical bonding.

Fueling station storage requirements will depend upon where the reformer is placed. If the reformer is placed on board the vehicle, then the fueling station needs to provide the fuel (methanol, gasoline, or natural gas) and take the appropriate safety measures for each. For this thesis, we consider the reformer will be placed at the fueling site. Steam reforming of natural gas could occur on site or via pipeline.

5.4.1 Compressed Hydrogen

Compressing hydrogen is similar to compressing natural gas, although the lower relative density of hydrogen requires compressors to have better seals. Hydrogen is normally compressed from 200 to 250 bar for storage in cylindrical tanks of up to 50 liters. These tanks may be made from aluminum or graphite reinforced compounds and can be used for either small industrial projects or transportation. If the compressed hydrogen is to be used on a larger scale, then pressures of 500-600 bar may be employed, although some of the largest compressed hydrogen tanks in the world (about 15,000 cu meters) use pressures of only 12-16 bar. Compressed hydrogen has been successfully demonstrated in multiple vehicles to date including Ballard's Fuel cell bus in Chicago (Chicago Transit Agency 1997-2000) and the Ford P2000 prototype and refueling station in Michigan.

5.4.2 Liquid Hydrogen

In order to reduce the volume required to store a useful amount of hydrogen - particularly for vehicles - liquefaction may be employed. Since hydrogen does not liquefy until it reaches -253°C (20 degrees above absolute zero), the process is both long and energy intensive. Up to 40% of the energy content in the hydrogen can be lost. The advantage of liquid hydrogen is its high energy: mass ratio, which is three times that of gasoline. It is the most energy dense fuel in use (excluding nuclear reactions), which is why it is used in all space programs. However, it is difficult to store and the insulated tank required may be too large and bulky for onboard storage.

Liquefied hydrogen systems have been demonstrated in multiple vehicles, most recently in DaimlerChrysler's NECAR 4.

5.4.3 Metal Hydrides

Metal and liquid hydrides and adsorbed carbon compounds are the principal methods of bonding hydrogen chemically. They are the safest methods as no hydrogen will be released in the event of an accident, but they are also bulky and heavy. Metal hydrides such as FeTi compounds are used to store hydrogen by bonding it to the surface of the material. To ensure that large volumes of hydrogen can be stored it is essential to use small granules of the base material to make a large surface area available. The material is 'charged' by injecting hydrogen at high pressure into a container filled with the small particles. The hydrogen bonds with the material and releases heat in the process, and this heat must be put back in to release the hydrogen from its bond.

There are various methods for storing and transporting hydrogen in its several states, as a gas, liquid, or metal hydride. The selection of a method of storing hydrogen will impact the design of the fueling station. When evaluating the method of storing hydrogen, it is essential that the fleet manager design a system that incorporates the technology of the vehicle, the method of providing fuel to the bus, and delivery of the fuel.

- 1) ***Stationary Large Storage Systems:*** Typically storage devices are at the production or transport level. The majority of these are near the start or end of pipelines and other transportation pathways. The stored hydrogen generally has to move through some type of plant (a compressor or refrigerating device) to permit operation of the storage cycle. In pressure-type storage devices for example, the gas pressure must be increased to permit a discharge depth, or in liquid hydrogen storage systems to accomplish liquefaction.
- 2) ***Stationary Small Storage Systems:*** At the distribution or final user level a storage system is necessary to meet the demand of an industrial plant. Most likely in liquid form and transported over small distances. In the case of relatively small demand as in an industrial application, hydrogen is reformed remotely and transported over short distances in liquid form.
- 3) ***Mobile Storage Systems:*** For transportation and distribution. They include; large capacity devices (liquid hydrogen tanker to a bulk carrier) and small capacity devices (liquid truck trailer) which are both mobile for ease of transport.

- 4) **Fuel Reservoirs:** mobile reservoirs can be used to store hydrogen road vehicles (automotive tanks). These must be able to withstand the heating and cooling effects required for the utilization of hydrogen onboard the vehicle. Adequate temperatures must be maintained to store hydrogen onboard the vehicle when it is not in operation.

Hydrogen can be stored, transmitted, and delivered to consumers using present gas transport technologies that are *similar* to natural gas. Hydrogen pipelines would be comparable to those for natural gas, although cost minimizing calculations for gas transport show that hydrogen pipelines will have larger diameters and fewer compressor stations. It has been suggested that during a transition period, it may be possible to use existing natural gas pipelines for hydrogen. Transporting hydrogen through natural gas pipelines has several concerns. Firstly, to avoid embrittlement, it would be necessary to check a particular pipeline to make sure that the steel was compatible with hydrogen. Secondly, because hydrogen has only one-third the energy density of natural gas, its compression power requirements are greater. Overall, the cost of transmission would be ~ 50% higher for hydrogen than for natural gas.⁴⁶ Thirdly, seals and special equipment such as monitors, meters and compressors would also need to be addressed or replaced. The use of natural gas pipelines as an intermediate solution to transporting hydrogen is a viable option, provided that older natural gas pipelines are replaced and new pipeline technologies are introduced to support and meet the requirements of hydrogen.

5.5 Why not Use Methanol?

Methanol is easier to store and handle than hydrogen, and easier to reform than gasoline, but methanol vehicles are more costly than hydrogen. Initially, a methanol infrastructure would be less expensive than an infrastructure for hydrogen due to the production costs associated with hydrogen. A switch from methanol to hydrogen might eventually occur, if hydrogen vehicles became lower in cost, and if the capital costs for developing a fuel production and delivery system proved to be lower for hydrogen than for methanol.

The optimum near-to-mid-term fuel strategy for fuel cell vehicles is uncertain. The results of both fleet and vehicle demonstrations of alternative fuel cell vehicle types is mixed, although technology demonstrations using hydrogen have proven to be successful.⁴⁷ In the long-

⁴⁶ Burnham, Laurie, ed. "Renewable Energy, Sources for Fuels and Electricity," New York: Island Press, 1993, pg 992.

⁴⁷ The Chicago Transit Authority demonstrated the feasibility of three hydrogen-powered fuel cell buses in regular use for a two-year experiment. These buses were made by Ballard Inc. of Vancouver and cost \$1.4

term, it appears that hydrogen has advantages over gasoline and methanol in terms of cost, complexity, fuel economy, and environmental benefits. Total capital cost for implementing a hydrogen-refueling infrastructure is comparable to, or less than, the total cost for methanol or gasoline fuel cell vehicles.⁴⁸ Hydrogen is the preferred fuel for fuel cell vehicles for reasons of vehicle design, cost and efficiency, as well as potential energy supply and environmental benefits.

In the short term, developers of hydrogen technology have yet to persuade industry, consumers, and fleet managers of the significant economic and environmental benefits. The near and mid-term outlooks for hydrogen is uncertain as scientists, experts, and engineers determine the economic feasibility of hydrogen as fuel. Numerous questions that lie outside the economic and financial barriers to fuel cell introduction will need to be addressed. Technology demonstrations – through fleet use – will provide a substantial amount of evidence of the technology’s feasibility and practicability in society outside of economic constraints. Demonstrations allow for the development of technical expertise, provide for increased regulatory pressures through increasing the ‘best available technology’ threshold, and illustrate to fleet managers the potential requirements and benefits of a fleet transition to hydrogen fuel.

million each. Chicago has no current plans of purchasing the buses but plan to buy cleaner-burning diesel buses at a cost of \$250,000 each. The demonstration of hydrogen fuel cell buses in Chicago has proven that buses operated on hydrogen are capable of functioning in a regular daily routine, as well as in the heat of the summer and chill of the winter.

⁴⁸ Ogden, Joan. *Journal of Power Sources*, 79 (1999) ppg. 143-168.

Chapter 6: The Importance of Safety and the Need for Standards

6.1 Safety

The public perception is that hydrogen is a dangerous, inflammable, and explosive gas. This is true. However, the full truth is that *all* fuels are dangerous, inflammable and explosive. Hydrogen has had particularly bad press. The Hindenburg disaster, in particular, has influenced public perception of hydrogen over the last sixty years and has demonstrated the severity of a hydrogen explosion. In this case, hydrogen was the igniter, and the materials used in construction were the fuels to create the explosion. Rigorous testing has led to the belief amongst many experts that hydrogen is no more dangerous than any other fuel - gasoline, natural gas, kerosene - and in many cases hydrogen is safer.⁴⁹ Nevertheless, this early disaster has cast a long shadow over hydrogen technology and it has taken years to reclaim its stature as a possible alternative propulsion fuel. The future use of hydrogen may require a precautionary approach to dealing with public perceptions of health and safety. In order for hydrogen to be widely accepted as fuel, attitudes towards its safety must be considered equal or better to that of conventional gasoline.

Because of hydrogen's properties (See Table 6.1) and the bad press to which hydrogen is accustomed, companies producing or using hydrogen must ensure extensive safety procedures are in place. Air Products and Chemicals Inc., and Praxair Inc., are two of the major companies producing commercially available hydrogen. These companies must adhere to proper storage, containers, transport, and handling of hydrogen. If gasoline automobiles were to be introduced now, rather than having evolved over the past 100 years, the safety requirements would probably have been much more stringent than they actually are today.

⁴⁹ The wide ignition and low minimum ignition energy of hydrogen-air mixtures are not the outstanding safety problems, as often depicted. In realistic accident situations the lower ignition limits are of primary importance, and they differ very little for hydrogen and natural gas; these values are even lower for propane than for hydrogen. The very low minimum ignition energy for hydrogen in air is insignificant as far as safety is concerned because even the so-called weak ignition sources release more energy than is necessary to ignite natural gas. (Winter and Nitsch)

Table 6.1 Properties of Hydrogen

Property	Hydrogen	Methane	Propane	Gasoline
Specific Gravity at NTP Relative to Air	0.07	0.55	1.52	~4.0
Normal Boiling Point (k)	20.3	111.6	231	310 to 478
Critical Pressure (ATM)	12.8	45.4	41.9	24.5 to 27
Density of liquid at NTP (Kg/L)	0.0708	0.4225	0.5077	~0.70
Density of gas at NTP (Kg/m ³)	0.838	0.6512	1.96	~4.40
Density Ratio, NTP Liquid/NTP Gas	845	649	2.59	~150
Diffusion Coefficients in NTP Air (cm ² /s)	0.61	0.16	0.1	~0.05
Diffusion Velocity in NTP Air (cm/s)	~2	~0.51	~0.34	~0.34
Quenching Gap in NTP Air (mm)	0.64	2.03	1.78	2
Limits of Flammability in Vol. (%)	4 to 74	5.3 to 15	2.1 to 10.4	1 to 7.6
Limits of Detonation in Air Vol. (%)	18.3 to 59	6.3 to 13.5	3.4 to 35	1.1 to 3.3
Minimum Energy for Ignition in Air (mJ)	0.02	0.29	0.305	0.24
Auto-ignition Temperature (K)	858	813	740	501 to 744
Flame Temperatures in Air (K)	2318	2148	2243	2470
Maximum Burning Velocity in NTP Air (cm/s)	278	37 to 45	43 to 52	37 to 43
Energy of Stoichiometric Mixture (MJ/M ³)	3.58	3.58	3.79	3.91

G.A. Karim, " Some Considerations of the safety of Methane, (CNG), as an Automotive Fuel-Comparison with Gasoline, Propane and Hydrogen Operation," SAE Paper N. 830267

Fuel cells also pose risks and create new demands for infrastructure. For instance, hydrogen is extremely flammable and has wide exposure limits. Hydrogen is a tiny molecule that is difficult to seal and prevent leakage. The wider the flammability limits the greater the chance of ignition in a release where sources of ignition are present.

Large quantities of hydrogen involve increased hazards. Although safety advocates emphasize hydrogen's low-ignition energy and its tendency to deflagrate in enclosed spaces, the truth is that hydrogen is highly explosive only when contained in confined spaces, and this is due to its high flame speed. The shape of the space in which the hydrogen is confined also plays an important part, as does the mode of ignition. However, hydrogen has a very high dispersion coefficient that make explosions very unlikely in open areas.

Storing hydrogen as a high-pressure gas requires extremely high temperatures. The required tank capacity compared to that of an energy equivalent gasoline tank is about 20 times

larger, where as the same amount of stored hydrogen corresponds to about 1-2% of the weight of an iron-titanium hydride storage tank.⁵⁰

The basis of all safety considerations in the manufacture, transport, storage and use of combustible energy carriers is the determination of their ignition, combustion and potential detonation behaviour, and the associated pressure build-up in accident situations. Accidents, which can lead to the formulation of ignitable mixtures, are usually triggered by fuel leakage caused by material defects, embrittlement, corrosion, mechanical overload, construction defects, collisions (with vehicles) and insufficient maintenance. Due to the importance of safety concerns of hydrogen, liquid hydrogen fueled buses may be banned from tunnels and limited to specific roadways. LNG and LPG vehicles are now usually banned from tunnels for fear of potential explosion.

With the widespread use of hydrogen in the energy supply system, one of the most important safety protection goals is, therefore, to protect a deflagration from turning into a detonation in rooms, pipeline systems and containers. Inherently working mechanisms are therefore of outstanding importance in hydrogen energy safety technology and there are promising possibilities.

“Liquid hydrogen spilling from a large rupture in a large storage tank would be dramatic: the liquid hydrogen, its temperature well below the usual ambient temperature, would quickly draw heat from the surroundings and vaporize rapidly. The cold hydrogen gas would occupy about 50 times the volume it did as a liquid. As the cold gas continued to draw heat from its surroundings and to warm up, water vapor in the chilled surrounding air would condense or freeze and form a white cloud of fog. As the volume of hydrogen gas warmed it would continue to expand when it became less dense than the chilled air surrounding it, it would rise buoyantly above the spill. In an open environment, the gas would diffuse quickly.”⁵¹

A key point regarding safety is that all chemical fuels including natural gas, gasoline, and hydrogen are potentially dangerous and must be handled properly, and when appropriate precautions are taken, all these fuels can be produced, stored, and transmitted safely. Hydrogen is no more dangerous than many other fuels (See Table 6.2). Its different characteristics require different safety equipment and procedures, but all fuels have some potential for accidents.

⁵⁰ Winter, Carl-Jochen and Joachim Nitsch. “Hydrogen as an Energy Carrier”, 1988.

Table 6.2 Health and Safety of Fuels

	Emissions	Health & Safety
Gasoline	CO, CO ₂ , NO _x , SO _x , VOC's and PM.	Extremely flammable, highly volatile, and risk of explosion. Evaporates quickly and leaves little residue when spilled. Contains high proportion of hydrocarbons, which can harm the nervous system.
Diesel	Emits lower amounts of reactive hydrocarbons and CO. Emits lower amounts of NO _x , however, burning diesel fuel increases PM. Diesel has 90 times as much sulfur as gas. Operates at lower temperatures than gasoline engines.	High flash point. Safer than gasoline. If spilled, it is not likely to spread on water.
Natural Gas	Has lower CO emissions, virtually no PM, and reduced VOC's. Per unit of energy, natural gas has less carbon than any other fossil fuel, leading to lower CO ₂ emissions per unit.	
Petroleum Gas	Propane vehicles can have lower emissions of reactive hydrocarbons (almost a third less) NO _x (20% less) and CO (60% less) than gasoline vehicles.	If LPG leaks or is spilled, it will remain on the ground or enter water systems.
Methanol	Smog-forming emissions are generally 30-50% lower; NO _x and hydrocarbon emissions from M-85 vehicles are similar or slightly lower. Total toxic air pollutants suspected or known to cause cancer can be 50% less with M-85, and non-existent with M-100. However, CO emissions are usually equal or slightly higher than gasoline vehicles.	Highly toxic. Safety concerns with ingestion, eye or skin contact, and inhalation.
Ethanol	Has approximately 30-50 less smog forming emissions than a gasoline vehicle. Air toxics are also reduced about 50 percent when compared to gasoline. Ethanol also offers significant greenhouse gas benefits, particularly when produced from renewable, high cellulose feedstocks.	
Hydrogen	When combusted (oxidized), only water vapor is produced. When burned in an internal combustion engine, small amounts of nitrogen oxides and small amounts of unburned hydrocarbons and carbon monoxide are produced, due to the use of engine lubricants.	Hydrogen is highly flammable, and there is a high risk of explosion. It has large blast effects and is easily ignited. Hydrogen is non-toxic. Because of hydrogen's lightness, any fuel leak rapidly disperses with no pooling of vapors. Hydrogen displaces air, so any release in an enclosed space could cause

⁵¹ Dickson, Edward. "The Hydrogen Economy: A Realistic Appraisal of Prospects and Impacts," New York: Praeger Publishers, 1977.

		asphyxiation.
Electric	None	Proper handling and disposal of batteries.
Biodiesel	The emissions from using biodiesel are much lower than diesel fuel. Biodiesel has no aromatic content and only trace amounts of sulfur. In vehicle tests, it has lower emissions of carbon monoxide, soot, and polycyclic aromatic hydrocarbons than conventional diesel. NOx emissions can be higher, but with adjustments in the injection engine timing, it is possible to reduce the NOx emissions. In addition, particulate emissions are essentially eliminated.	Biodiesel is biodegradable and nontoxic, making it an excellent fuel for marine applications. In addition, biodiesel has a high flash point and it does not produce explosive air/fuel vapors.

Several basic measures were indicated through demonstration projects that minimize dangers in the vehicle and the infrastructure. Provided safety measures are observed, there are no greater risks involved than those associated with diesel.

Table 6.3 Fire Safety Comparison by Fuel Type

	Gasoline	Diesel	Methanol	Hydrogen
Ignition: Open	Highest	Lowest	Middle	High
Ignition: Closed	Lowest	Middle	Highest	Highest
Relative Heat Release Rate	4.9	4.5	1.0	1.0
Flame Luminosity	High	High	Nearly Invisible	Nearly Invisible

Source: "Table 5 – Fuel Fire Safety Comparison", "Fuel Choices for Fuel Cell Powered Vehicles", Paul Berlowitz and Charles Darnell, SAE 2000-01-0003.

An analysis of possible malfunctions during the demonstrations has revealed that all possible faults must be analyzed as comprehensively as possible with regard to the specific hazards posed by hydrogen. Fleet managers and operators must ensure that strict preventive measures are taken when using hydrogen as fuel.

- Prevent flammable or explosive gas-air mixes
- Prevent leakage of hydrogen supply system
- Prevent high pressure build up in storage system
- Protect storage system from external forces
- Protect passengers from contact with hydrogen (liquid)

- Conform to legal limits on pollutant emissions.

Extreme cold of liquid hydrogen can severely damage or kill living tissue. Exposure to hydrogen will be involuntary once a transition to a hydrogen economy begins. Consequently, pressures for stringent regulation regarding hydrogen use can be expected to develop.

Moreover, the buildings or facilities used for storing, loading, and maintaining alternative fuel vehicles as well as fuel storage form an important portion of fleet operation. The experience with federal and state fire and building codes for alternative fuels are not yet complete. This situation requires additional care on the part of the owners of these facilities to recognize all hazards associated with the use of alternative fuel build up and to ensure that these hazards are properly addressed in the design and operation of the facility.

Experience has shown that not all local community and regulatory groups view the use of alternative fuels as a purely positive option. Public perceptions of the safety of hydrogen may be one of the major obstacles to the transition to a hydrogen economy. Transit properties and others who propose the use of alternative fuels need to deal not only with the perceptions of fire and building code officials who grant approvals, but also with the perceptions and concerns of community and neighborhood organizations. The concerns of these groups are not limited to fleet operations, but may also include the production of the alternative fuel and the transportation of the fuel to the point of use.

In view of the diversity of these safety concerns, as well as the number of possible hazards, a comprehensive and systematic program is needed to recognize and organize the existing knowledge about the health, safety, and environmental hazards of alternative fuels and to identify where additional study is needed. Part of the development and introduction process of a hydrogen fuel station will require industry and government to respond to all questions surrounding public safety and to deal with them appropriately. However, even with a sharp increase in the amount of hydrogen used in future industrial processes, no new safety problems are expected ⁵² provided appropriate standards and safety measures are followed. This will be an essential component to the introduction of a hydrogen fueling station.

6.2 Standards, Codes and Zoning Requirements

Codes, standards, regulations, and other similar criteria developed, adopted, and implemented at the international, national, state, and local levels will have an impact on the

⁵² Winter, Carl-Jochen and Joachim Nitsch. "Hydrogen as an Energy Carrier"

design, construction, application, and use of hydrogen-based technologies. Whether for vehicular, portable, or stationary applications, fleet managers involved with fuel cells and other hydrogen producing or using technologies will have to pay particular attention to codes, standards, and regulations.

The National Hydrogen Association (NHA), in conjunction with its members and other parties, and with support from the U.S. Department of Energy (DOE), is participating in the codes, standards, and regulations process. The ‘Hydrogen Safety Source’ book developed by DOE, CANMET, and NASA is being revised to make it suitable for local code officials and fire marshals as a major reference source. The International Standards Organisation (ISO) has also approved standards for connectors, high-pressure storage tanks, liquid storage tanks, and fuel specifications.⁵³ The International Code Council is responsible for the development of new building, fuel and fire safety codes for commercial and private structures. The National Hydrogen Association is also still working with the NFPA (National Fire Protection Association) to enable siting of hydrogen refuelling stations. Building code officials in the U.S. will likely require NFPA documentation. The development of a hydrogen fueling station would require the following codes and standards to address hydrogen as fuel and as an energy system.

- Local Uniform Administrative Code
- Uniform Fire Code
- NFPA50A Standard for Gaseous Hydrogen Systems at Consumer Sites
- NFPA50B for Liquid Hydrogen at Consumer Sites.
- NFPA69 Standard on Explosion Prevention Systems
- NFPA70 National Electric Code
- NFPA497A Hazardous Locations for Electrical Installations in Chemical Process Areas
- OSHA Standard No. 1910.103 Hydrogen

A discussion is required that focuses on the safety issues associated with the public using a refuelling station that dispenses hydrogen, natural gas, and gasoline, as well as the various differences in fuel pressures, must be addressed. Several gases, such as gasoline and methanol have been used safely in industrial settings, and substantial data exists on their flammability and toxicity. While the public is accustomed to the dangers of using gasoline through decades of experience, methanol, natural gas, and hydrogen, have not seen wide use by the public. Issues regarding safety, toxicity, accidents, and contamination must be adequately addressed to ensure the safe handling of hydrogen in a new environment.

⁵³ Gronich, Sig. “Energy Resources R&D Portfolio Analysis 2000: Producing Clean Fuels,” Hydrogen Production and Systems, US DOE, February 23, 2000.

Another regulatory and safety issue that must be addressed is the maintenance of pipelines and storage tanks. The need to obtain data on the integrity of the tank and lining degradation is essential to ensuring proper storage and safety. The integrity of the tank lining needs to be known to assess loss of strength. There are many non-destructive techniques used to measure tank and cylinder wall thickness. Questions pertaining to maintenance personnel, scheduling and inspection and repair locations still remain to be answered.

Work must continue on other issues related to siting. According to Dave Conover of the Pacific Northwest National Lab, current building codes consider the reforming of natural gas to hydrogen in the production facilities to be a hazardous operation. This type of zoning problem needs to be addressed. Co-ordination with building codes, CNG (compressed natural gas) managers, model building codes (IBCO, ICC, BOCA), and fire marshals are essential if hydrogen refueling stations are to be sited on public property.⁵⁴

Appropriate measures must also be designed for the transportation of fuel on highways, in tunnels, and in populated urban environments. Standards and zoning requirements for the transport of alternative fuels and the designation of specific pathways for transport (i.e. specific routes for trucks to follow) should be similar to those of existing standards of fuels, such as natural gas.

6.3 Public Awareness and Training

In order to operate a bus in a public transport system under realistic conditions, all measures must be coordinated with the entire bus fleet and management team; the scheduled route should be analyzed for possible incidents by the fire department and the police before the start of the line operation. Finally, extensive training sessions for the driving and workshop staff by representatives of the transit agency must also be part of the preparation for the operation phase of the hydrogen bus. Particular emphasis should be placed on safety aspects (safe handling of hydrogen, especially liquid hydrogen) and on driving practices and refueling.

Public awareness and training is perhaps one of the most important aspects for success of a hydrogen fueling station demonstration. If sufficient information is not provided to the public and they do not understand the context in which hydrogen is used, opponents to a hydrogen fueling station will emerge. The affiliation of hydrogen with the Hindenburg disaster represents the effects that an accident may have on the introduction of alternative fuel technology. Many people may not immediately link hydrogen fuel to what happened at Hindenburg, however those

⁵⁴ <http://www.ttcorp.com/nha/advocate/ad34note.htm>

who do may refer to the explosive properties of hydrogen and oppose any development of its use in public transportation. To address the explosive politics of hydrogen, it is therefore essential to address all public concern with regard to its use and safety.

Chapter 7: The Next Five Years?

7.1 Issues with Hydrogen Fuel Cell Introduction

The issues surrounding fuel cell technology introduction are not necessarily complex. The technology has been demonstrated and research and development is continually improving the products and processes required for fuel cell introduction. Ultimately, the question becomes simply a matter of willingness – Can industry and fleet managers change or adapt current operations to a hydrogen fueling system at their facilities? Are they willing to make the change now or will it take further regulation, cost increases, and or political motivation to get them to act? What steps would address their concerns and who would take these steps? Can the change happen in the next five years?

Government, industry, fleet managers, operators, and the public must all be involved to successfully make the transition to a hydrogen fueling station in the next five years. To conclude, I identify eleven obstacles that can slow or stop the introduction of hydrogen and other alternative fuel and suggest a tiered strategy that addresses these barriers.

7.2 Barriers to a Hydrogen Fueling Station

1) Information

People, both as citizens and as consumers, lack information about the problems posed by auto-mobilization, in terms of environmental impacts and societal costs. They are also largely ignorant of the real costs to them for each kilometer driven. Industry lacks information about the mobility needs of individuals and businesses that might be met by available technologies. There is a lack of information about the costs and benefits of implementing new relevant technologies. Economic attractiveness must be considered since consumers tend to focus on the posted prices and pay less attention to energy density or energy use efficiency. Consumers are willing to pay for cleaner fuel, provided they know that everyone shares the financial burden equally. Alternative fuels like hydrogen, cause concern to those who lack information on the properties and the experience of past use of hydrogen.

2) Technology

Fuel cell technology has been demonstrated to be technologically feasible. NASA's experience combined with growing industry interest (Ballard, Plug Power, SatCom) has demonstrated fuel cell technology for public and private transportation use. However, there is

substantial technological knowledge missing with regards to the applicability of fuel cells in all methods of transportation and infrastructure requirement. Research has access to limited design tools, and often focuses and relies on technological fixes instead of solutions to environmental problems.

3) Financial

Cost is one of the most significant barriers to the introduction of a hydrogen fueling station. Access to funding is extremely limited. Fleet managers are operating with limited buses and when forced with decisions to either replace an entire fleet of buses with alternative fueled buses or to spend money fixing older buses, the decision is usually to fix those they have. Government subsidies offered to fleet managers provide some funds to purchase new vehicles but it is often not enough. Fleet managers usually have alternative priorities. Increased private and public partnerships to obtain financial support could alleviate some of the financial burden as well as provide increased support to change transit priorities.

4) Information and Educational Barrier:

The dissemination of information to both fleet managers and the general public regarding the feasibility of using hydrogen as fuel has been slow. The lack of information has left the public uninformed about the potential alternatives to gasoline and the possibilities of contributing to environmental initiatives and improvements. There has also been a limited opportunity for education and training of fleet managers and individuals about the properties of hydrogen as fuel and its potential use in transportation.

5) Understanding

If the effects of implementing specific measures are to be anticipated accurately, better understanding of the movement of people and freight is required. Much is known about people and cars, but less is known about general travel patterns and energy use for transportation. Understanding the role of the car in people's lives is needed to provide adequate substitutes. The demand for new fuel will depend on what image it has and how it is positioned in the market place. Deciding to switch an entire fleet of buses in downtown Los Angeles will require a cost-benefit approach be presented to those who use the system and to those who would be interested in using an alternative method of transportation should one become available.

6) Commitment

A proactive approach and commitment from individuals, government, and society at large to the needs of future generations is necessary to profit from the benefits of technology change. Absence of a shared vision or set of values about the environment places limits on the potential for change. The benefits of hydrogen as fuel mainly eliminating mobile sources of air pollution will not actually be seen for many years. Nevertheless, action is required now to improve air quality.⁵⁵ Very short-term motivations of government and the desire to avoid introducing unpopular measures, especially if they are not an immediate necessity, act as a significant barrier to the introduction of hydrogen as fuel.

7) Resources

The lack of available resources reduces the many opportunities of achieving extraordinary changes. Resources, including political will, research and development, funding support, and time all reduce opportunities to try innovative energy-efficient technologies and to achieve behavioral changes in transport modes and distances traveled.

8) Policy

Traditional command and control responses to air quality and air pollution have placed limits on our ability to innovate. Inadequate or inappropriate regulation and response, has left industry to take a 'wait-and-see' approach before investing heavily in alternative technologies and before stepping in to make the necessary changes to their current business practices. A lack of enforcement by regulators, a relaxed approach to setting standards for those unable to comply, and the indecisiveness of government has led to the development of confusing and time-consuming decision making. The lack of political objectives and policies to secure energy and raw materials for future use in transportation has created a barrier to determining the alternative source of fuel for the future. The general lack of political decision-making and strategic long-term planning has created a significant barrier to the introduction of alternative fuel, like hydrogen, as a potential energy system in the future.

Political Challenges of the future⁵⁶

⁵⁵ The same argument is said for Global Warming. Does it exist? Do we waste time in trying to decide whether or not the problem exists, if it does what is the main contributor. Or do we start looking at solutions so that years from now when push comes to shove, we know we did or can do something about to fix the problem.

⁵⁶ Howitt, Arnold. "Controlling Auto Emissions: Policy and Politics," Presentation at MIT, March 4, 2000.

- “Vertical” fragmentation – multiple levels of government divide authority and responsibility, creating multiple veto points,
- Federal influence is limited and exercised indirectly in both policy arenas (transportation and environment)
- Federal institutions conduct the research and state institutions are given the responsibility for implementation and action,
- “Horizontal” fragmentation – transportation and air quality institutions are separate, loosely coupled through general government oversight, wary of each other.
- Two other policy subsystems that are functionally connected – land use regulation and energy – are also loosely coupled and are not linked through the framework of CAAA and ISTEA.
- National policies must fit problems that have enormous variety in different locals – i.e., as a function of geography, meteorology, economic and social life, cultural values, existing transportation infrastructure,
- Geographic scope of the physical systems of transportation and the air quality do not correspond to the boundaries of any units of government,
- Scientific uncertainty about the operation of the physical systems and empirical uncertainty about the character of the problem in particular places.

9) Appropriate Government Behaviour

The automobile industry is concerned with the lack of clear long-term and clear objectives and the presence of about contradictory regulations that distort competition, delay innovation, and hamper industry’s quest to be cost effective. With unpredictable regulations, a system developed to meet currently known requirements can become suddenly obsolete. Also, the lack of international uniformity of regulations creates an attitude of “why should we do it if no one else is”. It is the role of government to reduce and or eliminate any uncertainty regarding a radically cultural change and acceptance of an alternative fuel infrastructure.

The development of a hydrogen energy system will ultimately depend upon the political will to move toward a zero emission energy system, and on the relative economics of hydrogen versus other low polluting alternative fuels. If in the presidential election this fall, a president is elected who comes from Texas, whose family owns several oil companies, what happens to those subsidies if they affect the oil industry? The debate of whether or not we should move towards zero or low emissions energy system is not the issue, but rather who will be the champion to stand up and see it through congress. Will the politics of hydrogen outweigh the politics of oil?

Building the demand for hydrogen will take time and early infrastructure to support a hydrogen energy system may have to be built in increments.

Although both air pollution and energy security are serious problems, public policy has focused far more on air quality than on fuel economy. The only recent federal policy regarding fuel economy has been the Program for the Next Generation of Vehicles (PNGV), which calls for voluntary effort by the major automobile manufacturers to produce a vehicle prototype that will get three times the average fuel economy.⁵⁷

CARB has proposed guidelines for programs establishing mobile source emission reduction credits. Under these programs air quality regulators would issue credits to those purchasing vehicles that exceed the emissions reductions required by law. These credits could be traded, and thereby provide incentives for the purchase of fuel cell buses.

10) Socio-Cultural

If the economy or society changes rapidly will we demand and consume more products? The resistance to change to an alternative system of fueling or alternative vehicles shows that most of society is unwilling to change its current processes and products for alternatives that will not provide them with the same level of service and satisfaction. The introduction of new technology is severely affected by the social implications of individual voting behaviors. Although hydrogen may be the best alternative fuel available, if consumers fear the technology will be too dangerous and expensive, they will be unlikely to vote for a politician who supports the introduction of this technology. Without the support of consumers and a cultural shift in attitudes, technological change will be limited.

The central problem for decision-makers is finding the balance between the benefits of the motor vehicle and its costs. Voters place high value on environmental quality but also want to retain the benefits of a lifestyle to which unrestricted mobility is a key element. Good policy design implies clarity about objectives combined with a willingness to be flexible about the means of meeting those objectives, while systematically monitoring the extent to which program goals are being achieved.

11) Safety

Need to build experience with safe operations to build public confidence and counter linger memories of “The Hindenburg”. Coordinated bus fleet and management team;

examination of possible incidents by the fire department, police, and emergency response personnel. Extensive training sessions for staff and comprehensive training material. Particular emphasis should be placed on safety aspects (safe handling of hydrogen, especially liquid hydrogen) and on driving practices and refueling.

Public awareness is essential to provide the public with the information needed to understand the context in which hydrogen is used. The Hindenburg disaster represents the effects that an accident may have on the introduction of alternative fuel technology. The reference to the explosive properties of hydrogen may prevent the introduction of hydrogen as fuel. It is therefore essential to address the public concern of the use and safety of hydrogen.

7.3 Strategy for Implementation

Establishing a hydrogen fuel cell bus fueling station

The design of the fuel cell vehicle must be weighed against the added complexity and cost of developing a hydrogen-refueling infrastructure. The technologies to produce, deliver and dispense hydrogen are well known. There appear to be no major technical hurdles to dispensing hydrogen transportation fuel. Ample supplies of hydrogen exist in the Los Angeles area. Near-term demonstration projects will help educate the technical issues for various types of fuel cell vehicles.

If a large market for hydrogen transportation fuel were to develop, industrial gas suppliers have indicated that they could build a large, new hydrogen plant based on steam reforming of natural gas in 2 – 3 years. Hydrogen could be liquefied for truck delivery or delivered via a small-scale pipeline system.

A Tiered Strategy for Implementing a Hydrogen Fueling Station for Buses

Tier One: Bus Demonstration

- A. The demonstration of the fueling station for hydrogen fuel cell buses will determine the engineering issues, technical difficulties, training and safety requirements, and operating costs. The SunLine Transit Agency and the California Fuel Cell Partnership are currently conducting hydrogen fleet demonstrations.

⁵⁷ The California program is critical to the commercialization of fuel cells. Currently, federal tax credits are available for the purchase of electric and hybrid vehicles. Regulations giving incentives to zero or low emission buses will have an immediate effect.

- B. Plan accordingly for hydrogen as fuel. Production and reforming of fuel will need to be carefully evaluated (Gas, Methanol, Natural Gas, etc.).

Tier Two: Build Low Capacity Demonstration

- A. Purchase hydrogen fuel cell buses or convert CNG fleet buses to hydrogen.
- B. Create agreements between chemical suppliers for sufficient supply of hydrogen.
- C. Determine methods of monitoring daily operations.
- D. Run continuously.
- E. Conduct extensive materials analysis from use of hydrogen.
- F. Check with experts and industry professionals to determine feasibility.

Tier Three: Expand to Entire Bus Line

- A. Use for hydrogen for light bus routes.
- B. Extend to longer routes and inter city routes.
- C. Determine range and horse power to evaluate further implementation.

Tier Four: Expand to Large Fleets, Trucks, and Increased Distances

Tier Five: Passenger Vehicles.

But how do we get from Here to There?

Other than cost, what would make fleet managers transition from using conventional petroleum fuels to implementing a hydrogen fueling station? This thesis has presented a program for demonstrating the feasibility of implementing a hydrogen fueling station. The fueling station represents the essential link for the infrastructure that is needed to support hydrogen fuel cell technology. All of the requirements of a successful program are in place: demand, financial support (government subsidy, institutional funding, collaborative industry alliances), fuel cell technology, and a bus fleet as a test medium. To unite these elements and move the program forward into the public domain, the driving force of a program architect, a driving force is absolutely essential. Proactive thinking, willingness to change, and a strong commitment of fleet managers are the determining factors that will lead fuel cells as the technology of choice for transit agencies in the next five years.

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9.0 Appendix

Appendix 1: Effects of Air Pollution

Air pollution is probably the most visible and pressing environmental consequence of our transportation system-and the one with which most people are familiar. (1) Transportation contributes up to 50 to 60 percent of air pollution nationwide and more than 50 percent of our air pollution in most urban and suburban areas. (2) In Los Angeles, for example, transportation generates between 70 and 80 percent of air pollution.

Most of the documented harm from air pollution results from the six "criteria" pollutants regulated by the U.S. Environmental Protection Agency (EPA).

Fossil fuels are the primary source of air pollution. Transportation is 97 to 99 percent dependent on fossil fuel.

Appendix 2: Clean Air Act Pollutants

CLEAN AIR ACT POLLUTANTS	Why is Air Pollution Important?
<p>Ozone – O₃ Volatile organic compounds (VOCs) and nitrogen oxides (NO_x) react in the presence of sunlight to produce ground level ozone. Ozone is commonly associated with urban smog</p>	<ul style="list-style-type: none"> • Lung inflammation • Reduced lung function • Coughing and breathing discomfort • Forest and crop damage
<p>Carbon Monoxide-CO Formed from incomplete combustion of fossil fuels and other organic materials.</p>	<ul style="list-style-type: none"> • Decreased learning ability and manual dexterity • Decreased exercise capacity • Impaired eye function
<p>Sulfur Dioxide-SO₂ Produced by burning fuel containing sulfur (mainly coal and oil), and during industrial processing. Contributes to acid rain and particulate matter formation</p>	<ul style="list-style-type: none"> • Increased hospital visits for respiratory illness • Breathing difficulty • Lake, forest, crop and building damage
<p>Nitrogen Dioxide-NO₂ (NO_x) Primarily a by-product of fossil fuel combustion and contributes to secondary formation of acid rain, ozone, and particulate matter.</p>	<ul style="list-style-type: none"> • Lung irritation • Reduced resistance to respiratory infection • Aquatic life destruction
<p>Particulate Matter-PM-10 Particulate matter "10" measures air particulates of 10 microns or less including dust, dirt, soot, smoke, and liquid droplets. Recent scientific data indicates the most harmful particles are 2.5 microns or less (the new proposed standard) which primarily come from fossil fuel combustion</p>	<ul style="list-style-type: none"> • Premature death • Increased risk of respiratory illness and cardiopulmonary disease • Lung cancer and decreased lung function • Building damage and reduced visibility
<p>Lead-Pb Since phasing out leaded gasoline, most lead emissions are localized near metal refineries</p>	<ul style="list-style-type: none"> • Altered neurobehavioral function • Increased blood pressure

PRIMARY GREENHOUSE GAS	Global Climate Change May Cause:
<p>Carbon Dioxide-CO₂ Produced primarily by fossil fuel combustion. CO₂ projected to contribute over 67% of enhanced global warming over the next century.</p>	<ul style="list-style-type: none"> • Increases in disease like malaria • Sea level rise • Intensified floods and droughts • Change in forest species composition

Appendix 3: Distribution of Emissions by Sector

Where is Air Pollution Coming From?				
Distribution of Emissions by Sector				
Source: Environmental and Energy Study Institute, 1997				
	Transportation	Electric Utilities	Industry	Other
Ozone	28% (VOCs) 41% (NOx)	<1% (VOCs) 29% (NOx)	50% (VOCs) 18% (NOx)	22% (VOCs) 12% (NOx)
CO	65%	<1%	9%	26%
Sulfur Dioxide	3%	66%	28%	3%
NOx	44%	33%	18%	5%
PM-10	1%	<1%	3%	96%
Lead	32%	1%	58%	9%
Carbon Dioxide	30%	35%	22%	13%

Appendix 4: Regulatory Requirements

California Air Resources Board (CARB)

The California Air Resources Board (CARB) is part of the California Environmental Protection Agency, an organization that reports directly to the Executive Branch of California State Government. CARB is the state agency responsible for improving and maintaining air quality in California. The primary goal of CARB is to provide healthful, clean air for all Californians and “To promote and protect public health, welfare and ecological resources through the effective and efficient reduction of air pollutants while recognizing and considering the effects on the economy of the state.”⁵⁸

CARB oversees all air pollution control efforts in California, including programs and activities of 35 local air pollution control districts. The Board has the authority and responsibility of ensuring that federal and state health-based air quality standards are achieved for stationary, mobile, and small "area" sources of pollution. These include: factories, power plants, cars, trucks, buses, off-road vehicles, consumer products, lawn and garden equipment, and other sources of air pollutant emissions.

Major Goals of CARB

- Provide Safe, Clean Air to All Californians
- Protect the Public from Exposure to Toxic Air Contaminants
- Provide Leadership in Implementing and Enforcing Air Pollution Control Rules and Regulations
- Provide Innovative Approaches for Complying with Air Pollution Rules and Regulations
- Base Decisions on Best Possible Scientific and Economic Information
- Provide Quality Customer Service to All ARB Clients

Primary Responsibilities of CARB

State law entitles CARB the responsibility for the implementation of specific programs in order to comply with the State and Federal Clean Air Acts, as well as for oversight of the local air district programs. In addition to CARB authority and responsibility of Air Quality in California, CARB also promotes research and development programs for cleaner technologies to combat toxic air emissions and improve air quality in California. CARB is involved in a variety of programs: motor vehicles, stationary applications, consumer products, and cleaner fuels. The development of a cleaner fuels program allows

⁵⁸ <http://www.arb.ca.gov/>

“the dual benefit of immediate emission reductions from vehicles currently on the road while also enabling new vehicles to meet increasingly more stringent standards.”⁵⁹

Corporate Average Fuel Economy (CAFE)

The federal government’s Corporate Average Fuel Economy (CAFE) regulations have been in force since 1978 and require vehicle manufacturers to achieve specified sales-weighted fuel-intensity averages for fleets of new cars and light trucks. The program, enacted in 1975 through the Energy Policy and Conservation Act, persists despite great shifts in energy prices, changes in the geopolitics of world oil, and the mounting empirical evidence that doubt CAFE’s efficiency on achieving energy conservation. Mileage per gallon (mpg) in these new fleets has improved but the longevity of older vehicles and the volume of use contribute to a significant annual increase in petroleum consumption in transportation.

First of all, the regulatory scheme takes aim at motor vehicles, but does nothing to discourage their use. A second drawback to the program is its impact on the overall stock of vehicles. The program has an effect on the miles per gallons (Mpg) of newly manufactured automobiles, and they compare favorably when evaluating the poor performance of older cars. Finally, the changing composition of the vehicular stock has frustrated the goals of CAFE in another way – as sagging fuel prices lower, the operating costs of light trucks, vans, and sport utilities have increased in sales and amount to more than 30 percent of the US market. With lower mpg standards for this growing segment of the passenger fleet, the average fuel economy, even for the newest vehicles, has not progressed as rapidly as it would have if a suitable fuel tax had been imposed.

CAFE’s effect on total fuel consumption has been attenuated by the increase in driving and in the average age of vehicles on the road that the regulations have partly encouraged.

South West Air Quality Commission

The Air Quality Management District (AQMD) in California is the air pollution control agency for the four-county region including Los Angeles and Orange counties and parts of Riverside and San Bernardino counties. This area of 10,743 square miles is home to more than 15 million people--about half the population of the State of California. It is the second most populous urban area in the United States. The AQMD is responsible for controlling emissions from stationary sources of air pollution. These can include anything from large power plants and refineries to the corner gas station. Emission standards for mobile sources are established by state or federal agencies, such as the California Air Resources Board and the U.S. Environmental Protection Agency, rather than by local agencies such as the AQMD.⁶⁰

⁵⁹ <http://www.arb.ca.gov/>

⁶⁰ <http://www.aqmd.gov/news1/Background.htm>

Appendix 5: CA EPA News Release – February 24, 2000

**California Environmental Protection Agency
News Release
Air Resources Board
February 24, 2000**

ARB Cuts Emissions from Transit Buses

SACRAMENTO -- The California Air Resources Board (ARB) today adopted a regulation that will further reduce air pollution from the state's transit buses, and require some fleet operators to start using zero-emission buses (ZEBs) in three years.

"This regulation cuts air pollution right where it is most troublesome -- in the heart of our cities where 90 percent of Californians live," said ARB Chairman Dr. Alan Lloyd.

The regulation, which in 2002 starts its phase-in, affects about 8,500 buses at approximately 75 California transit agencies.

It moves forward in several steps over the next ten years, requiring cleaner engines, cleaner diesel fuel, retrofit to reduce exhaust particulate matter (PM) emissions from older diesel buses, use of ZEBs and reduced exhaust PM and nitrogen oxides (NOx) from new diesel engines. Diesel exhaust PM contributes to mortality and contains substances known to cause cancer, while NOx contributes to ozone, the main harmful component of urban smog.

The regulation allows transit agencies the flexibility of choosing between either a diesel or alternative fuel "path" to lower air emissions. Agencies may choose to use low-emission alternative fuels such as compressed or liquefied natural gas, propane, methanol, electricity, fuel cells or other advanced technology. Continued use of diesel brings with it a requirement to use low-sulfur (15 parts-per-million) diesel fuel beginning July 1, 2002, and cut emissions from new diesel buses by another 75 percent beginning in 2004. An even lower NOx standard applies to both diesel and alternative fuel bus engines sold to California transit agencies starting in 2007.

In addition, for both diesel and alternative fuel paths, a NOx fleet average of 4.8 begins in 2002, which will require some transit agencies to retire their oldest, highest polluting buses. A requirement to retrofit existing buses with traps or other devices to reduce PM starts in 2003. When the requirements are fully implemented, all transit buses will be smoke-free and will emit less smog forming emissions.

"The regulation is designed to bring quick, near-term emissions reductions and long-term, near-zero emission benefits," Dr. Lloyd said.

Large transit agencies with 200 or more buses that continue to purchase primarily diesel vehicles are required to begin demonstrating the use of at least three ZEBs by 2003.

ZEBs powered by electricity or hydrogen fuel cells are already being used by some transit agencies.

From model year 2008 through 2015, large transit agencies using diesel will be required to make ZEBs 15 percent of their new bus purchases/leases. For large transit agencies using primarily alternative fuels, the 15 percent ZEB rule runs from model year 2010 through 2015.

And, since federal, state and local governments heavily subsidize bus costs, it is possible to invest in purchases of new, cleaner buses without adversely affecting transit service.

ARB staff calculates that the new transit bus rules, combined with normal fleet turnover, will bring statewide reductions of seven-tons-per-day of NOx and 12 tons-per-year of PM by 2020.

We have made available the "Urban Transit Bus Fleet Rule Requirements and Emission Standards" below in Word97 and PDF format ([MSW97 - 23K](#)) or ([PDF - 13K](#)).

The Air Resources Board is a department of the California Environmental Protection Agency. ARB's mission is to promote and protect public health, welfare, and ecological resources through effective reduction of air pollutants while recognizing and considering effects on the economy. The ARB oversees all air pollution control efforts in California to attain and maintain health based air quality standards.

Appendix 6: Design Guidelines for Bus Transit Systems Using Hydrogen

**USDOT FTA
DOT FTA – MA – 20 – 7021 –98-1
“Clean Air Program: Design Guidelines for Bus Transit Systems Using Hydrogen as
an Alternative Fuel”
Office of Research, Demonstration, and Innovation
October 1998, Final Report.**

Standards

The following NFPA standards can be obtained from the National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy MA 02269-9101 or by calling 1-800-344-3555.

- NFPA 50A -- Standard for Gaseous Hydrogen Systems at Consumer Sites (1994 Edition).
- NFPA 50B -- Standard for Liquefied Hydrogen Systems at Consumer Sites (1994 Edition).
- NFPA 54 -- National Fuel Gas Code. This code is a safety code that shall apply to the installation of fuel gas piping systems, fuel gas utilization equipment, and related accessories.
- NFPA 70 -- National Electric Code. The purpose of this code is the practical safeguarding of persons and property from the hazards arising from the use of electricity.
- NFPA 88A -- Standard for Parking Structures. This standard covers the construction and protection of, as well as the control of hazards in, open, enclosed, basement, and underground parking structures. This standard does not apply to one- and two-family dwellings.
- NFPA 88B -- Standard for Repair Garages. This standard covers the construction and protection of, as well as the control of hazards in, garages used for major repair and maintenance of motorized vehicles and any sales and servicing facilities associated therewith.
- NFPA 497A - Recommended Practice for Classification of Class I Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas. This recommended practice applies to locations where flammable gases or vapors, flammable liquids or combustible liquids are processed or handled and where their release to the atmosphere may result in their ignition by electrical systems or equipment.

The primary standards that apply specifically to hydrogen systems are NFPA 50A and NFPA 50B. These industry consensus standards stipulate the requirements for the design of hydrogen systems (including containers, pressure relief devices, equipment assembly, marking, etc.), location of hydrogen storage areas, operation and maintenance, fire protection and other safety requirements. No specific standards exist for vehicular hydrogen fueling systems, requirements for operation of vehicles, specification for the vehicle storage and maintenance buildings.

The focus of the Occupational Safety and Health Administration (OSHA) regulations in 29 CFR, g 1910. 103 is primarily the safety of the worker in a plant that stores or uses hydrogen. Substantial parts of these regulations are adaptations of the various requirements in NFPA 50A and NFPA 50B. In this document, the various requirements from NFPA Standards are referred to and the exact language from the relevant sections is cited where necessary.

Appendix 7: Public Transit Bus Fleet Rule and Emission Standards for New Urban Buses

Adoption of a Public Transit Bus Fleet Rule and Emission Standards for New Urban Buses

(January 27, 2000 Hearing) Description: This regulatory proposal is intended to further reduce emissions of both ozone precursors and toxic air contaminant's from the California urban transit bus sector. California is the only state that has the authority, under both state and federal law, to establish motor vehicle standards different from federal standards. These standards must be equivalent to or more stringent than the federal standards. This regulatory proposal contains: a) a multi-component urban transit bus fleet rule applicable to transit agencies; and b) more stringent emission standards for new urban bus engines applicable to manufacturers of such engines.

Affected Regulations: Amendments to title 13, section 1956.8, CCR and the incorporated "California Exhaust Emission Standards and Test Procedures for 1985 and Subsequent Model Heavy-Duty Engines and Vehicles," and proposed adoption of new sections 1956.1, 1956.2, 1956.3, and 1956.4 of title 13, CCR

Status: The Hearing Notice was published December, 10, 1999, for a Hearing on January 27, 2000 at 9:30 am in the South Coast Air Quality Management District auditorium in Diamond Bar, California. The regulatory proposal and public testimony were heard at the January 27, 2000 Hearing. At that time the item was closed to further comments and was set to be continued at the next Hearing on February 24, 2000 at 9:30 am at the Air Resources Board Hearing Room in Sacramento.

<http://www.arb.ca.gov/regact/bus/appena.pdf>

Appendix 8: Section 1956.2, Title 12, CCR

SECTION 1956.2, TITLE 13, CCR

**Add to Title 13, California Code of Regulations, new section 1956.2, to read:
1956.2 Fleet Rule for Urban Transit Bus Operators**

- (a) To encourage transit agencies that operate urban bus fleets to purchase or lease currently available lower emission alternative-fuel buses, while also providing flexibility to such fleet operators to determine their optimal fleet mix in consideration of such factors as air quality benefits, service availability, cost, efficiency, safety, and convenience, two paths to compliance with this fleet rule are available: the alternative-fuel path and the diesel path. Transit agencies must choose their compliance path, and those choosing the alternative-fuel path shall notify ARB of their intent to follow that path, by January 31, 2001. Reporting requirements for that notification are set forth in subdivision (a)(1) of section 1956.4, 13 CCR.
- (b) Transit agencies on the alternative-fuel path shall meet the following requirements:
 - (1) Upon approval of the regulation, and through Model Year 2015, 85 percent of all urban buses purchased or leased each year must be alternative-fuel buses.
 - (2) NO_x fleet average requirements as set forth in subsection (d), below.
 - (3) Beginning October 1, 2002, engines certified to an optional PM standard of 0.03 g/bhp-hr or lower shall be used.
 - (4) PM retrofit requirements and use of low sulfur fuel as set forth in subsection (e), below.
 - (5) Zero emission bus purchase requirements beginning in model year 2010, in accordance with the requirements in section 1956.3, 13, CCR.
 - (6) Reporting requirements as set forth in section 1956.4, 13 CCR.
- (c) Transit agencies on the diesel path shall meet the following requirements:
 - (1) NO_x fleet average requirements as set forth in subsection (d), below.
 - (2) PM retrofit requirements and use of low sulfur fuel as set forth in subsection (e), below.
 - (3) Zero emission bus demonstration in 2003-2004, as required in section 1956.3.
 - (4) Beginning January 1, 2004, transit agencies on the diesel path shall not take delivery of any buses certified to emissions levels in excess of those specified in subdivision (a)(9) of section 1956.1, 13 CCR.
 - (5) Zero emission bus purchase requirements beginning in model year 2008, in accordance with the requirements in section 1956.3, 13 CCR.
 - (6) Reporting requirements as set forth in section 1956.4, 13 CCR.
- (d) Beginning October 1, 2002, no transit agency shall own, operate, or lease a fleet of urban buses with average NO_x emissions in excess of 4.8 g/bhp-hr, based on new or repowered engine certification standards.
 - (1) This fleet average requirement shall be based on urban buses owned, operated, or leased by the transit agency, including diesel buses, alternative-fuel buses, all heavy-duty zero emission buses, electric trolley buses, and articulated buses, in their fleet.

- (2) Transit agencies may use ARB-certified retrofit systems to comply with the fleet average equipment (in addition to bus purchases, repowerings, and retirements).
 - (3) Transit agencies have the option of retiring all 1987 and earlier model year diesel urban buses by October 1, 2002, to comply with the fleet average standard requirement.
- (e) To reduce public exposure to diesel particulate matter, transit agencies and companies that lease buses to transit agencies shall participate in a program to retrofit diesel buses in their fleet, and to operate their diesel buses on diesel fuel with a maximum sulfur content of 15 parts per million. Documentation of compliance with these requirements must be provided in accordance with the provisions of subdivision (c) of section 1956.4, (f) 13 CCR.
- (1) By January 1, 2003, transit agencies shall not own, operate or lease 1990 and earlier model year diesel, dual fuel, or diesel hybrid buses in their active fleet, unless those buses have been retrofitted as provided in (A), below, or are eligible for an exemption as provided in (B), below. Transit agencies with less than 20 buses in their active fleet, and that operate in federal ozone ambient air quality standard attainment areas, are subject to this requirement beginning January 1, 2007.
 - (A) The retrofit must be certified by the ARB as having an 85 percent or greater efficiency in reducing diesel particulate matter. 1990 and earlier buses were originally certified to a PM standard of 0.60 grams per brake horsepower-hour. Only those 1990 and earlier buses that have been retrofitted to 0.10 grams per brake horsepower-hour PM with an ARB-certified retrofit device (to meet the requirements of the U.S. EPA urban transit bus rebuild and retrofit program, 85CFR, sections 1401 through 1415) are eligible for the retirement exemption provided in subsection (e)(4), below.
 - (2) Transit agencies shall not own, operate or lease 1991 through 1995 diesel, dual-fuel, or diesel hybrid transit buses in their active fleet, unless the buses have been retrofitted according to the requirements and schedule set forth in paragraphs (A) through (D), below. Transit agencies with less than 20 buses in their active fleet, and which operate in federal ozone ambient air quality standard attainment areas, are exempt from paragraphs (A) and (B), and subject to paragraph (C) beginning January 1, 2007.
 - (A) 20 percent of these buses shall be retrofitted by January 1, 2003.
 - (B) 75 percent of these buses shall be retrofitted by January 1, 2004.
 - (C) 100 percent of these buses shall be retrofitted by January 1, 2005, except for those buses eligible for the retirement exemption in subsection (e)(4), below.
 - (D) The retrofit must be certified by the ARB as having an 85 percent or greater efficiency in reducing diesel particulate matter.
 - (3) Transit agencies shall not own or operate 1996 through 2003 diesel, dual-fuel, or diesel hybrid buses in their active fleet, unless the buses have been retrofitted according to the following requirements:
 - (A) 20 percent of these buses shall be retrofitted by January 1, 2007.
 - (B) 75 percent of these buses shall be retrofitted by January 1, 2008.

(C) 100 percent of these buses shall be retrofitted by January 1, 2009, except for those buses eligible for the retirement exemption in subsection (e)(4), below.

(D) The retrofit must be certified by the ARB as having an 85 percent or greater efficiency in reducing diesel particulate matter.

(4) Transit agencies must meet the 100 percent retrofit requirements in subsections (1)(B), (2)(C), and (3)(C), above, except for those buses that are within two years of retirement. Those buses within two years of retirement are exempt from the retrofit requirements, and retirement of the exempt buses must be documented in accordance with section 1956.4(c)(2), below.

(5) Beginning July 1, 2002, transit agencies shall not operate diesel buses on diesel fuel with a sulfur content in excess of 15 parts per million.

(A) Transit agencies with less than 20 buses in their active fleets, and which operate in federal ozone ambient air quality attainment areas, are not subject to this requirement until July 1, 2006.

NOTE: Authority cited: Sections 39600, 39601, 43013, 43018 Health and Safety Code. Reference: Sections 39002, 39003, 39017, 39500, 39650, 40000, 43000, 43000.5, 43013, 43018, 43801, 43806 Health and Safety Code, and sections 233, 28114, 27157 Vehicle Code.

Appendix 9: Section 1956.3, Title 13, CCR

SECTION 1956.3, TITLE 13, CCR

Add to Title 13, California Code of Regulations, new section 1956.3, to read:

1956.3 Zero Emission Bus Requirements

- (a) "Zero emission bus" means an Executive Officer certified urban bus that produces zero exhaust emissions of any criteria pollutant (or precursor pollutant) under any and all possible operational modes and conditions.
 - (1) A hydrogen-fuel cell bus shall qualify as a zero emission bus.
 - (2) An electric trolley bus with overhead twin-wire power supply shall qualify as a zero emission bus.
 - (3) A battery electric bus shall qualify as a zero emission bus.
 - (4) Incorporation of a fuel-fired heater shall not preclude an urban bus from being certified as a zero emission bus, provided the fuel-fired heater cannot be operated at ambient temperatures above 40 B F and the heater is demonstrated to have zero evaporative emissions under any and all possible operational modes and conditions.
- (b) Zero Emission Bus Demonstration Project – except as provided in (3) below, the owner or operator of an urban bus fleet on the diesel path in accordance with the provisions of section 1956.2, with more than 200 urban transit buses in its active fleet on January 31, 2001, shall implement a demonstration project. The owner or operator shall evaluate the operation of zero emission buses in revenue service, and prepare and submit a report on the demonstration project to the Executive Officer for inclusion in a future review of zero emission technology.
 - (1) This demonstration project shall meet all of the following specifications and requirements:
 - (A) utilize a minimum of three zero emission buses,
 - (B) include any necessary site improvements,
 - (C) locate fueling infrastructure onsite,
 - (D) provide appropriate maintenance and storage facilities,
 - (E) train bus operators and maintenance personnel
 - (F) place the buses in revenue service for a minimum duration of 12 calendar months,
 - (G) retain operation and maintenance records, and
 - (H) report on the demonstration program as set forth in subdivision (d) of section 1956.4, 13 CCR. A-11
 - (2) When planning and implementing the demonstration project, the operator or owner shall meet the following milestones:
 - (A) no later than January 1, 2002, prepare and solicit bid proposals for materials and services necessary to implement the demonstration project, including but not limited to the zero emission buses and the associated infrastructure
 - (B) no later than July 1, 2003, place at least three zero emission buses in revenue service, and
 - (C) no later than January 31, 2005, submit a report on the demonstration project to the Executive Officer, in accordance with section 1956.4 (d)(3), 13 CCR.

- (3) Multiple transit agencies within the same air basin may, on a case-by-case basis, petition the Executive Officer to implement a joint zero emission bus demonstration project. Electric trolley buses shall not qualify as zero emission buses for purposes of this joint demonstration project. No more than three transit agencies can participate in any one joint project. Transit agencies that are participating in a joint demonstration project shall:
- (A) designate the agency hosting the onsite demonstration,
 - (B) jointly fund the demonstration project,
 - (C) place a minimum of three zero emission buses per participating transit agency in revenue service,
- (c) Purchase Requirement for Zero Emission Buses - The owner or operator of a transit agency with more than 200 urban buses in active service on January 1, 2007, for transit agencies on the diesel path, and January 1, 2009, for transit agencies on the alternative-fuel path, shall purchase and/or lease zero emission buses, in accordance with the following:
- (1) For transit agencies on the diesel path, in accordance with the requirements in section 1956.2, a minimum 15 percent of purchase and lease agreements, when aggregated annually, for model year 2008 through model year 2015 urban buses shall be zero emission buses.
 - (2) For transit agencies on the alternative-fuel path, in accordance with the requirements in section 1956.2, a minimum 15 percent of purchase and lease agreements, when aggregated annually, for model year 2010 through model year 2015 urban buses shall be zero emission buses.
 - (3) The provisions of paragraphs (1) and (2) shall not apply if the operator's urban bus fleet is composed of 15 percent or more zero A-12 emission buses on January 1, 2008, for transit agencies on the diesel path, and on January 1, 2010, for transit agencies on the alternative-fuel path, or at any time thereafter.
- (d) The Air Resources Board shall review zero-emission bus technology and the feasibility of implementing the requirements of section (c) above no later than January 2006. Based on that assessment, the Board shall decide whether to proceed with the implementation of the requirements.

NOTE: Authority cited: Sections 39600, 39601, 43013, 43018, 43100, 43101, 43104, 43806 Health and Safety Code, and sections 27157 Vehicle Code. Reference: Sections 39002, 39003, 39017, 39018, 39500, 39701, 40000, 43000, 43000.5, 43009, 43013, 43018, 43102, 43801, 43806 Health and Safety Code, and sections 27157 and 28114 Vehicle Code.

Appendix 10: Section 1956, Title 13, CCR

SECTION 1956.4, TITLE 13, CCR

Add to Title 13, California Code of Regulations, new section 1956.4, to read:

1956.4 Reporting Requirements for all Urban Bus Transit Agencies and Leasing Companies

- (a) The following reports on new bus purchases and/or leases by transit operators on the alternative-fuel path shall be submitted as described below:
 - (1) The initial report shall be submitted by January 31, 2001 and shall state the transit agency's intent to qualify for the alternative-fuel path.
 - (2) Any requests for deviation from the requirement that 85 percent of buses purchased per year must be alternative-fuel buses must be submitted in writing and approved by the Executive Officer of the Air Resources Board 90 days prior to purchase.
 - (3) Transit agencies shall maintain, and produce upon request, records regarding: the number, model year, and fuel used for engines in transit buses they currently own or operate, bus purchases and/or leases beginning January 1, 2000, annual average percentage of total bus purchases and/or leases that were alternative-fuel buses.
- (b) The following reports on the NOx fleet average requirement shall be submitted as described below:
 - (1) initial documentation shall be submitted by January 31, 2001, and contain, at a minimum, the active urban bus fleet NOx emission average, and if that number exceeds the required average, a schedule of actions planned to achieve that average by October 1, 2002, including numbers and model years of bus purchases, retirements, retrofits, and/or repowerings, or, indicate the intent to retire all model year 1987 and earlier buses in their active fleet by October 1, 2002.
 - (2) a final report shall be submitted by January 31, 2003, detailing the active urban bus fleet NOx emission average as of October 1, 2002, and actions, if any were needed, taken to achieve that standard, including numbers and model years of bus purchases, retirements, retrofits, and/or repowerings, or documenting the retirement of all model year 1987 and earlier buses. A-14
- (c) The following reports on the PM bus retrofit requirements shall be submitted as described below:
 - (1) initial reports shall be submitted by the dates shown below and shall contain, at a minimum, the following information:
 - (A) number and model year of diesel buses in the active fleet, projected number and model year of buses to be retrofitted annually, projected number and model year of exempt buses, if any, and basis for exemption.
 - (B) a report for Tier 1 and Tier 2 requirements shall be submitted by January 31, 2002.
 - (C) a report for Tier 3 requirements shall be submitted by January 31, 2005.
 - (2) transit agencies shall maintain, and produce on request, records of number and model year of diesel buses in the active fleet, number and model year of buses

retrofitted per year, retrofit devices used, number and model year of exempt buses, if any, and basis for exemption.

(d) The following reports on the zero-emission bus demonstration program shall be submitted by those transit agencies required to conduct such demonstrations as described below:

(1) initial documentation shall be submitted by January 31, 2003, and contain, at a minimum, the bus order and delivery schedule, fuel type, type of refueling station, any planned facility modifications, and a revenue service demonstration plan

(2) a financial plan shall be submitted by January 31, 2003, and contain, at a minimum, projected expenditures for capital costs for purchasing and/or leasing buses, refueling stations, any facility modifications, and projected annual operating costs

(3) a final report shall be submitted by January 31, 2005, and contain, at a minimum, the following information:

(A) a brief description of the zero emission technology utilized, identification of bus manufacturer and product specifications,

(B) miles driven per bus in revenue service, safety incidents, driver and mechanic training conducted, and maintenance (both scheduled and unscheduled), A-15

(C) qualitative transit personnel and passenger experience, and

(D) a financial summary of capital costs of demonstration program, including bus purchases and/or leases, fueling infrastructure, any new facilities or modifications, and annual operating costs.

(e) The following reports on new zero-emission bus purchases and/or leases shall be submitted by transit agencies required to purchase zero-emission buses as described below:

(1) initial report shall be submitted by date shown below, and contain, at a minimum, the following information:

(A) a brief description of the zero emission technology to be utilized and a plan for the implementation of the requirement,

(B) for an exemption from the purchase requirement, documentation that 15 percent or more of the transit agency's active urban bus fleet is composed of zero-emission buses.

(C) transit agencies on the diesel path shall submit report by January 1, 2007.

(D) transit agencies on the alternative-fuel path shall submit report by January 1, 2009.

(2) any requests for deviation from the requirement that 15 percent of buses purchased per year must be zero-emission buses must be submitted in writing and approved by the Executive Officer of the Air Resources Board 90 days prior to purchase.

(3) transit agencies on the diesel path shall maintain, and produce upon request, records regarding: the number, model year, and fuel used in engines they currently own or operate, bus purchases and/or leases beginning with model year 2008 and through model year 2015, annual average percentage of total bus purchases and/or leases that were zero-emission buses.

(4) transit agencies on the alternative-fuel path shall maintain, and produce upon request, records regarding: the number, model year, and fuel used in engines they

currently own or operate, bus purchases and/or leases beginning with model year 2010 and A-16 through model year 2015, annual average percentage of total bus purchases and/or leases that were zero-emission buses.

NOTE: Authority cited: Sections 39600, 39601, 39659, 39701, 43018, 41511 Health and Safety Code

Reference: Sections 39700, 39701, 41510, 41511, 43000, 43000.5, 43013, 43018, 43801, 43806 Health and Safety Code.

Appendix 11: Correspondence with Bill Clappers – SunLine Transit Agency

1. What experiences with CNG have been/or could be useful for the introduction of a hydrogen refueling station?

The following information is directly transferable from CNG to H2. *The transition to CNG from diesel required new training regarding how to work with high pressure systems, new types of refueling infrastructure, working with valves structures and large stationary compressors. One has to deal with "pull -aways" where someone inadvertently forgets to unhook the hose after the refueling is complete and drives off with the hose. There is more diagnostics involved with CNG than diesel and we expect the same with H2 but our mechanic have a higher level of training. In fact when we go out for new hires we look for automobile mechanic because they have more diagnostic training than diesel mechanics.*

2. What are the costs associated with switching from CNG to Hydrogen? What technical changes were most costly?

Because SunLine had made the initial switch to CNG we had a great deal of experience in the switch over. We are following a similar but unique of experience in the switch over. We are following a similar but unique model in that we are adding a Solar and Wind renewable component. *The costly components are the compressor and the storage systems.*

3. What is the cost of a Hydrogen Fuel Cell Bus vs. a CNG Bus?

The question is premature for now. *The manufacturing curve has not been achieved. Several tens of millions of dollars have been expended on just a few buses. We expect the learning curve to bring the bus into the \$600,000 range by 2008 vs. a \$330,000 CNG bus as of today. Today's CNG buses have "flatlined" in price which is a function of a large two buses is related to the fuel cell. The fuel cell will achieve lower cost when lower cost materials replace such materials as platinum and on a production line.*

4. Why would someone be interested in switching his or her CNG fleet to Hydrogen?

Hydrogen gets the carbon atom out of the energy resource and during its use produces only electricity and water. Continues the work to restore/improve the environment. After all the environment is a resource also - look at "Eco-Tourism". The trick is not to produce hydrogen using fossil fuels such as the grid or if the grid is used then the production emissions must be less than with the currently used fossil fuels. Therefore producing H2 from renewable resources or CNG stationary reformers are the promising routes.

5. What would happen if a Hydrogen fueled bus ran out of gas away from the refueling station? Are there different refueling requirements in terms of training, standards, fuel storage, etc?

SunLine Transit Agency has provisions for this on our CNG operations. We have many ways of handling. First all routes are planned regarding range issues. If a bus did run out of fuel we would dispatch our shop truck which has the capability of rescue. In fact one of our other vehicles rescued a Van yesterday because someone did not plan their trip in relation to the range of the CNG van. We would follow the same practice with H2. In fact

in the Coachella Valley AAA has a vehicle outfitted with CNG tanks for just rescues. The differences revolve around the characteristics of H₂. It burns with a clean flame so detectors must be in place at the fueling island. CNG has an odorant. H₂ does not. We follow the codes and standards of the National Fire Protection Association (NFPA). Differences are not that much if you go this way through the CNG path.

6. Are there any special requirements for the location of a hydrogen refueling station?

We are following the NFPA that outlines distances. Ours is being placed on the same public fuel island that we have for CNG.

7. What permits, standards, and codes are required for the storage, production, distribution, and use of Hydrogen as fuel?

These are listed in the NFPA that the Fire Marshals, Building inspectors and local building codes follow. The ones of most interest is what it will take in local communities to park "your" H₂ powered vehicle in your own garage.

8. What is cost of transporting Hydrogen via truck vs. pipeline to your facility?

We have no information on this since we will be producing our own H₂ but why not try Air Products or Praxair marketing offices.

9. Where will Hydrogen be stored at the fueling station? Underground?

It will be stored above ground. Because the storage pressures can go as high as 5,000psi, it is better to store above ground because a high-pressure release will dissipate the H₂ vertically into the atmosphere. If you want to know something funny the Insurance industry wants people to insure for a "H₂ Spill". How does one clean up something that dissipates?

10. Will the learning's from this demonstration be applicable to alternate locations. For example, will what you have learned be transferred to another location in the Northeast?

It can be directly transferable to the Northeast. We are in fact under agreement with a sister transit property in San Diego to transfer our technology base to them over the next three years.

11. What argument would you use to convince the politicians, fleet managers, and the public officials in Los Angeles that Hydrogen fuel cell buses are the next step in combating air emissions in California?

It is not the politicians that have to be convinced. It is the trucking and bus industries that must be convinced as well as the General Managers, Directors, Managers, Supervisors, Mechanics, and Operators. These are the people who make things work. If they do not believe and do not try to make it work - it won't work - just a bunch of kids who do not want to do what mom and dad (politicians) tells them to do. Automotive manufacturers are already positioning themselves for the future, as are the energy providers. They do not wish to be left with "stranded" capital.

12. There are several arguments against the use of CNG buses due to the amounts of particulates released and the inability to determine the toxicity of these particulates. How would you argue for or against this?

I am not a measurer of emissions but reductions in NOX and Sulfur Dioxides which are tremendously less must come from objective studies which have been done by lots of folks. The information from this question can only be coming from the diesel industry. Contact the South coast air Quality Management District in Diamond Bar, California. We no longer pay any attention to these arguments because are own experience does not consideration. We have other things to do than chase lost causes.

13. If there was one barrier to implementation of a hydrogen station other cost, what would you say it is?

Willingness to take a chance on new technology and new approaches to transportation. Progressive thinking.

Appendix 12: California – Health and Safety 43806 Transit Buses

43806. On or before January 1, 1993, the California state board shall adopt emission standards and procedures applicable to new engines used in publicly owned and privately owned public transit buses, and shall make the standards and procedures effective on or before January 1, 1996. The standards shall consider the engine and fuel as a system and shall reflect the use of the best emission control technologies expected to be available at the time the standards and procedures become effective. In adopting standards, the state board shall consider the projected costs and availability of cleaner burning alternative fuels and low-emission vehicles compared with other air pollution control measures.

(Added by Stats. 1991, Ch. 496, Sec. 2.)

Regulations: 13, CCR, Section 1956.8

Appendix 13: Chicago Transit Authority Bus Demonstration

Chicago - The field tests of the fuel cell buses at the Chicago [Illinois, U.S.A.] Transit Authority is yielding some valuable information for the next phase of development. The refuelling process has been simplified, allowing buses to be filled more quickly. Drivers have reportedly enjoyed the performance and the acceleration of the vehicles. Mechanics have been adapting well to the new technology with the help of extensive training and detailed manuals.

The only major change that has been implemented since the buses started running was to change from a fan to a water cooling system for auxiliary motors to maintain the temperature in response to the hot Chicago summers. One of the buses required minor repairs after mild “fender-bender” in the garage. All other systems have been running exceptionally well and routes have been serviced without delays.

Appendix 13: Automotive Fuel Cell Engine Developers

1. Daimler Benz

- *By most accounts, DB is the leading automotive fuel cell engine developer, is focusing on methanol for automobile fuel cell electric engines although hydrogen is still being pursued for bus fleet applications. This choice was made in part because a methanol steam reformer is considered more efficient and less difficult to reduce to an automotive component than a fuel processor for gasoline.*
- The expectation that the higher hydrogen content of natural gas (the current and prospective source of methanol) will more than compensate for the greater inefficiencies in methanol production, with the net result that, for the complete fuel supply-fuel cell engine system, carbon dioxide emissions will be lower for methanol than for gasoline.
- Daimler Benz believes that gasoline fuel cells would only be an intermediate step to systems using methanol and, in the long term, hydrogen.

2. General Motors

- GM's in-house fuel processor development program to date has emphasized methanol but gasoline is being pursued in parallel to keep open the possibility of technical breakthroughs and to guard against fuel cost and availability risks.
- GM does not consider any of the fuels being worked on entirely suitable, and the need for substantial investments in a supply infrastructure is anticipated not only for methanol but for gasoline as well since a gasoline-type fuel would need to be tailored for fuel cells, most likely at the refinery.
- GM believes that the feasibility of automotive fuel cells will benefit significantly from a move toward new petroleum distillate fuels with the highest possible hydrogen content and a chemical reactivity facilitating processing into a hydrogen-rich fuel gas

3. Ford

- Ford has the leading edge in developing environmental technology solutions as its Chairman, Bill Ford is a strong environmental advocate and supporter of clean 'green' automotive technologies.*
- Ford has created a new environmental division dubbed TH!NK, which will deliver everything from battery-powered urban runabouts to hydrogen fuel-cell cars and even electric bicycles. Although it will join other carmakers in offering hybrid vehicles, Ford is staking its longer-term future on fuel-cell cars, which use hydrogen to make electricity without combustion. Meanwhile, a more mainstream effort will focus on hybrid vehicles that combine electric motors with fuel-sipping conventional engines.
 - Ford recently opened the first hydrogen refueling station in North America. The station can refill vehicles with either liquid or gaseous hydrogen. It is the second refueling station in the world. The refueling station is located next to the Ford Research Laboratory in Dearborn, supplying hydrogen to a specifically equipped dynamometer lab. While primarily used for fuel cell development, Ford also is

conducting significant research on hydrogen-powered internal combustion engines.

4. Japanese Automobile Manufacturers

- Japanese car makers engaged in fuel cell development are focusing on methanol, for the same reasons as Daimler Benz: less difficulty in processing, a somewhat higher fuel efficiency of the fuel cell power plant, and reduced transportation energy system emissions of carbon dioxide.
- Finally, shifting transportation energy to methanol and, therefore, natural gas is in line with an energy security strategy that seeks reduced dependence on imported oil by broadening the transportation fuel base.

Partnership for a New Generation of Vehicles/DOE Fuel Cell Programs

Interest in gasoline as a practical fuel for automotive fuel cells was stimulated in large measure by Program for a New Generation of Vehicles, the collaborative program of the three major U.S. automobile manufacturers and several Federal Government agencies led by the Department Of Energy. Five years ago, the development of gasoline-powered fuel cells became one of the technical strategies to achieve a primary goal of PNGV: an advanced-technology, commercially competitive automobile capable of delivering 80 mpg, by 2004.

Oil Industry Involvement

Facing the possibility that fuel cell electric vehicles could emerge as an entirely new, major market either for gasoline or for a non-petroleum product such as methanol, the oil industry has become engaged in efforts to understand and influence the issues and decisions bearing on fuel choice. Traditional oil companies intend to remain energy companies no matter what form the energy might be. The purpose of this collaborative effort is to utilize the combined talents of the participants, to develop a knowledge base on the potential use of gasoline and/or other petroleum-derived fuels in automotive fuel cells, identify major barriers and pursue possible solutions.

Industry Use, and NASA

Fuel cells use an evolution of 1960's era space technology to chemically convert hydrogen and oxygen into electricity without combustion.⁶¹ Research at NASA on the use of hydrogen as a fuel is driven by the specific needs of major programs such as the Shuttle, the National Aerospace Plane, and others. Most of the work on these systems is unique to the specific application under development, but some of the technology is also of general use, particularly in the areas of storage and distribution, leak detection, and safety practices. NASA's budget for hydrogen R&D is spread over a number of programs and is difficult to separate from general engineering work on those programs. The Kennedy Space Center in Florida supplies liquid hydrogen for all other Federal users as well as that used by NASA itself. (70) On January 31, 1995, NASA officials dedicated a new fuel cell test-bed at Edwards Air Force Base in California for development of a

⁶¹ "Natural Gas Best Source of H₂ for FCV's," Canadian Newswire, March 21, 2000. (<http://www/V3/newsfeedca/stories/>).

regenerative fuel cell system that directly converts hydrogen fuel and oxygen into electricity and water. The water produced is stored and then regenerated back to hydrogen and oxygen by means of a solar-powered electrolyzer.

In the Department of Defense, the annual budget for hydrogen production and storage research is estimated to be less than \$1.5 million. This amount is distributed over several research centers, under both the Navy and the Air Force. DOE is a member of the Hydrogen Implementing Agreement of the International Energy Agency (IEA). Participation in IEA's programs on Hydrogen Production and Hydrogen Conversion, Storage, and Safety is intended to help monitor international research results and factor them into U.S. efforts.

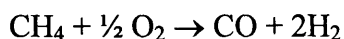
Appendix 14: Methods of Hydrogen Production

Steam Reforming:



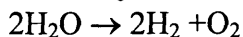
Steam reforming is a chemical process that makes hydrogen from a mixture of water and a hydrocarbon feedstock, usually a fossil fuel (natural gas, methane, etc.). When steam and methane are combined at a high pressure and temperature, a chemical reaction converts them into hydrogen and carbon dioxide. The energy content of the hydrogen produced is actually higher than that of the natural gas consumed, but considerable energy is required to operate the reformer, so the net conversion efficiency is typically about 65 percent.⁶² Hydrogen produced by this technique can cost as little as \$0.65 per kilogram.⁶³ It is generally recognized that steam reforming of natural gas provides the least expensive hydrogen and that hydrogen production costs for chemical processes escalate in the following order.

Partial Oxidation



The partial oxidation process yields 30 percent hydrogen gas directly and 20 percent carbon monoxide. Then, the carbon monoxide is chemically reacted with steam to produce additional hydrogen and carbon dioxide gas, which is readily usable by a hydrogen fuel cell. This fossil-to-hydrogen fuel system would be used as a "bridge" until R&D yields a commercially ready advanced hydrogen storage system or a suitable hydrogen carrier.⁶⁴ Methods such as the Fischer-Tropsch process, are currently being used to create synthetic petroleum and diesel fuels that may be used in the interim until hydrogen is commercially available. A mixture of hydrogen and carbon monoxide is reacted in the presence of an iron or cobalt catalyst. An extensive use of heat is involved, and such products as methane, synthetic gasoline and waxes, and alcohol are made, with water or carbon dioxide as by-products. Only when electrolysis comes into the picture as an approach which has been technically successful where it has been economically justified.

Electrolysis of Water



Electrolysis means passing an electrical current through water to split individual water molecules into their constituent hydrogen and oxygen. Electrolysis attracts attention because it is a clean process and water is abundant (best results are obtained from the distilling the water and removing any contaminants such as sulfur prior to electrolysis). Energy losses during this process are relatively modest: 65 percent energy efficiency is

⁶² Appleby, A. John. "Hydrogen as a Transportation Energy Vector", First NHA Meeting, p. 7-6.

⁶³ Moore and Nahmias. "Gaseous Hydrogen Markets and Technologies," pg. 11-7. Their estimate is based on a plant producing 250,000 kg per day, with a natural gas cost of \$2.00 per million Btu.

⁶⁴ Morgan, Daniel and Fred Sissine. Congressional Research Service Report for Congress "Hydrogen: Technology and Policy," 95-540 SPR, April 28, 1995.

common, and state-of-the-art large electrolyzers can be 80 to 85 percent efficient.⁶⁵ Electrolysis has captured considerable attention, even though it accounts for only a small fraction of current hydrogen production. At present, however, the technique is only used at relatively small plants, with a cost of \$2.40-\$3.60 per kilogram of hydrogen produced.⁶⁶ Because it is very expensive, it is expected to be limited to niche markets in the near and mid term. Cost effective and environmentally sound bulk scale electrolysis, would require cheap electricity from a non-hydrocarbon source such as nuclear, hydropower, wind or direct solar. The availability of cheap hydropower has contributed to the strong Canadian interest in hydrogen as fuel. It has been suggested that a small electrolyzer serving a single neighborhood or filling station could compete favourably with steam reforming, since steam reforming's cost advantages only hold for large production volumes. Electrolysis may also play a role in making the transition to increased hydrogen use.

Several arguments have been made that the prospects for water electrolysis will improve only under conditions that do not exist so far but are expected to rise in the future. These conditions- pressure to reduce CO₂ emissions, the opening up of unusually cheap hydro power energy reserves, the construction of new large nuclear electric power plants as well as the prospect of linking photovoltaic plants in distant regions with electrolytic hydrogen factories – are viable technologies for using electrolysis but remain heavily dependent upon demand and significant economies of scale as well as the ability to provide adequate storage to supply fuel, before the implementation of large electrolysis production.

The competition between hydrogen as fuel and electricity (battery) is based largely upon the basis of production, distribution, and storage. If a super battery is developed, the electric vehicle will win since it could be run with renewable electricity and miss the losses associated with conversion to hydrogen and re-conversion into electricity in a fuel cell.

⁶⁵ Stuart, Alexander K. "A Perspective on Electrolysis," First NHA Meeting, pg. 13-4. Stuart states that efficiencies may climb to as much as 90 percent over time. Losses in the electrolyzer's ancillary electrical equipment however, may reduce the net efficiency by a few percent below these figures.

⁶⁶ Morgan, Daniel and Fred Sissine. Congressional Research Service Report for Congress "Hydrogen: Technology and Policy," 95-540 SPR, April 28, 1995.