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Hydrogen and Transportation – DRAFT Solicitation Comment

VNG Comments on Hydrogen and Transportation Solicitation

VNG is a Pennsylvania-based company that is developing a national public-access fueling network that will deliver compressed natural gas ("CNG") to light-duty natural gas vehicles ("NGVs") in the fleet and mass-market consumer segments. California, as a leader in clean alternative fuel adoption as well as the largest vehicle market in the country, will likely be one of the early states targeted in the company's build-out in major metropolitan areas nationwide.

VNG is also strongly interested in the development of the market for hydrogen fuel cell vehicles (FCVs) due to the numerous technical synergies between natural gas and gaseous hydrogen:

- **Hydrogen Fuel Production:** Natural gas is used as a feedstock for 95% of the hydrogen produced in the U.S. today, and distributed steam methane reforming (SMR) of natural gas is expected to be the lowest-cost technology for on-site production of hydrogen for the foreseeable future.

- **Fueling Station Design:** Equipment requirements for CNG and hydrogen fueling are broadly similar, and hydrogen can be blended with natural gas on-site to create cleaner-burning CNG blends that can be dispensed alongside pure hydrogen and pure CNG.

- **Vehicle Technology Development:** On-board fuel management and storage technologies for NGVs and FCVs are also shared, and the development of advanced storage technologies in particular can be accelerated by the aggressive commercialization of both gaseous fuels.

For these reasons, VNG believes that the successful mass-market deployment of NGVs can serve as a "bridge to hydrogen" from both a vehicle and infrastructure development perspective.[1] This linkage is particularly important with regards to fueling infrastructure, since the high costs of the equipment to compress, store, and dispense both types of gaseous fuels is one of the primary challenges they

[1] This "bridge to hydrogen" rationale was a core component of VNG's comments to EPA regarding the new 2017-2025 federal and California GHG emissions program, and is further detailed in the attached white paper "Natural Gas: An Essential Bridge to Hydrogen Fuel Cell Vehicles." EPA found this rationale sufficiently "persuasive" to award NGVs special "advanced technology" multiplier incentives. (See *2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards*, p. 22)

face. The robust development of CNG infrastructure has potential to lower the costs of hydrogen fueling station development in a variety of ways, through reduced equipment costs from economies of scale as well as potential savings from sharing of design, development and possibly even capital costs (for stations combining CNG and hydrogen dispensing).

Thus, like other CNG fueling infrastructure players, VNG is actively monitoring the development of the market for FCVs and will consider opportunities to participate in the hydrogen fueling business in California alongside the development of the company's core CNG fueling business. Given the central importance of the Commission's hydrogen fueling infrastructure funding to the development of the FCV market statewide – and, indeed nationwide, given California's unquestioned status as the focus of FCV commercialization efforts in the U.S. – VNG welcomes the opportunity to offer our perspective on the present solicitation.

Positive Aspects of the Solicitation

VNG is supportive of most aspects of the draft solicitation, and several areas in particular:

Retail-Oriented Stations: VNG concurs with the focus of the Commission's program on funding retail-oriented fueling stations within existing gasoline stations, with a goal of providing customers with a gasoline-like fueling experience. VNG is pursuing a similar strategy with its development of light-duty CNG infrastructure, and believes that providing a familiar, convenient fueling experience will be critical to facilitating mass-market adoption of gaseous fuels.

Support for "Multi-Fill" Configurations: The inclusion of "multi-fill" stations providing hydrogen fueling in addition to other alternative fuels will encourage innovation by companies like VNG that may explore ways to combine CNG and hydrogen fueling capability in a single station design. Scoring bonuses for "unique or advanced" design features may also serve to support such projects.

Emphasis on "Scalable" Stations: Lowering the minimum station capacity to 50 kg/day may help to encourage early participation in hydrogen infrastructure development, since it may allow for stations to be built without need for on-site production of hydrogen. However, the Commission's decision to emphasize the potential "scalability" of stations in its scoring process is appropriate for the goal of developing a robust hydrogen fueling network, and will help ensure that stations designed to accommodate higher capacities (likely requiring on-site hydrogen production with SMR or electrolysis) will be prioritized.

Flexibility in Meeting 33% Renewable Requirement: While there is substantial potential to meet the renewable content requirement for hydrogen production through direct physical pathways using biogas feedstock, VNG recognizes that there are currently limited quantities of suitable biogas resources available for this purpose. Allowing for compliance with this requirement through acquisition of LCFS-compliant credits instead is an important flexibility for maintaining the viability of stations using SMR for hydrogen fuel production – a pathway expected to be significantly lower in cost than electrolysis.

Negative Aspects of the Solicitation

VNG acknowledges the importance of the environmental impetus behind the statutory requirement imposed by SB 1505 for 33% renewable content in hydrogen production. However, VNG does not believe that it is appropriate for the Commission to offer incentives for station developers to go beyond this threshold, as this detracts from the primary goal of establishing a network of hydrogen fueling infrastructure capable of supporting automaker deployment of FCVs beginning in 2015.

Contrary to this, the draft solicitation provides incentives for additional renewable production through a $3 million set-aside for projects using 100% renewable hydrogen, and further encourages this objective through scoring preferences for increased renewable and/or low-carbon hydrogen under the 'Innovation' and 'Sustainability' criteria. Given the challenges that infrastructure developers will already face in meeting the goals of the California Hydrogen Roadmap outlined by the California Fuel Cell Partnership (CAFCP) ahead of 2015, the potential diversion of up to 16% of the $18.69 million available under this solicitation to 100% renewable projects (instead of potentially more-deserving projects that 'only' meet the 33% requirement) is not an optimal use of limited funding.

It is important to note that removing special funding and preferences for higher-than-required renewable content in this solicitation would not eliminate all incentives for lower-carbon hydrogen production. The Low Carbon Fuel Standard will give station developers a durable incentive to use renewable and low-carbon feedstocks for hydrogen, and the LCFS will provide stronger incentives over time as program targets become more stringent after 2020. Other incentive programs provide funding for renewable power generation and biogas production, and the state Renewable Portfolio Standard will guarantee a steady increase in renewable content for stations utilizing electrolysis.

The present solicitation should thus focus all of its funding on the primary goal of maximizing hydrogen capacity in key locations, and let station developers evaluate the use of additional renewable content based on the incentives already in place.

A Road Map for Future Hydrogen Funding

This solicitation is a positive step that will provide essential support for the further development of hydrogen fueling capacity in key areas identified by the CAFCP roadmap. However, in future solicitations, station developers may be encouraged to lower costs further through a transition to a "performance-based" incentive that offers funding based on installed hydrogen capacity – instead of basing funding solely on project costs, which does little to encourage cost-effective station design. Such an incentive structure would do more to encourage infrastructure developers with CNG expertise (including VNG) to pursue opportunities to deliver hydrogen at lower costs through integrated station design, shared equipment such as CNG/H2 multi-fuel dispensers, and other innovations. The model performance-base incentive developed by Energy Independence Now (EIN) and submitted under this docket is one example of this type of approach and one that VNG would support for use in future solicitations.

In closing, we urge the Commission to recognize that the ultimate goal of facilitating widespread adoption of hydrogen FCVs can be greatly facilitated by development of the full range of gaseous fuels, including CNG and biogas. The AB 118 Alternative and Renewable Fuels and Vehicle Technologies (ARFVT) program administered by the Commission has been a very important source of funding in the state for all alternative fuels, and a continuation of robust support for not only hydrogen but CNG and biogas as well will help to maximize opportunities for positive synergies between these technologies. The Commission may even wish to consider the inclusion of special incentives for projects that provide benefits for multiple program areas – for instance, combined CNG/H2 fueling stations, or the integration of biogas and hydrogen production.

VNG appreciates the opportunity to comment on this draft solicitation, and hopes to work with the Commission in the future to help encourage deployment of hydrogen *and* CNG refueling infrastructure and vehicles throughout the state.

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NATURAL GAS: AN ESSENTIAL BRIDGE TO HYDROGEN FUEL CELL VEHICLES

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The Road to Hydrogen Fuel Cell Vehicles

This report by Energy Futures, Inc. addresses natural gas vehicles (NGVs) as a bridge technology to fuel cell electric vehicles (FCEVs) in any advanced technology incentive program. Energy Futures, Inc. has studied the potential role of NGVs in the U.S. transportation market since the mid-1980s, with a focus on the synergies between natural gas and hydrogen as automotive fuels. It has researched and written a wide range of books, reports and professional papers on this topic. The report was funded by VNG.Co, a company based in Philadelphia, Pennsylvania, and committed to expanding the national vehicle fueling infrastructure for the delivery of compressed natural gas (CNG) and gaseous hydrogen transportation fuels. More information about Energy Futures, Inc. appears at the end of this report.

The Transition to Electrified Vehicles

The instant proposal reflects a strategy to go beyond simple GHG reduction targets to promote the replacement of conventional LDVs powered by internal combustion engines (ICEs) with those equipped with electric drivetrains. The transition to electrified vehicles is likely to be the most significant development in automotive history of the 21st century. Electric drivetrains are up to three times more energy efficient than conventional drivetrains, they have zero tailpipe emissions, and they can transmit the energy originally found in a wide range of renewable and fossil energy resources into vehicle power through the energy "carrier": electricity.

Most electrified vehicles under development today obtain electricity from the power grid and store it onboard in batteries. They are called battery or pure electric vehicles and are termed EVs. Fuel cell electric vehicles (FCEVs) are another form of electrified vehicle. They use electricity generated onboard through the electrochemical conversion of hydrogen to power electric motors. Unlike EVs, which obtain electricity by wire from stationary power plants, the electricity in FCEVs is generated pollution-free by onboard, mobile hydrogen fuel cells. Thus, hydrogen can be viewed as a second and complementary energy "carrier," like electricity. It, too, can be produced from a variety of fossil and renewable energy resources. Electric motors are indifferent to the source of electricity used to power them; it can be obtained from a battery or a fuel cell or from both in the case of a hybridized fuel cell drivetrain.

High energy efficiency is one of the key advantages of FCEVs compared to conventional ICE vehicles. According to the U.S. Department of Energy (DOE), the fuel efficiency of the FCEV drivetrain is at least twice as efficient as a conventional drivetrain.[1] When optimized, FCEVs could exhibit three times the efficiency of conventional vehicles, meaning that the same quantity of hydrogen will drive a vehicle up to three times further when it is used in a fuel cell powering an electric drivetrain rather being burned in an ICE. Supplying hydrogen to a fuel cell rather than an ICE cuts transportation energy demand dramatically, and lessens the challenges and costs of storing hydrogen onboard vehicles.

Like EVs, PHEVs can be recharged by wire from the electricity grid and they have the ability to be propelled solely by electricity from an onboard battery, although for only relatively short distances. Once the stored electricity is depleted, a PHEV switches to its conventional drivetrain and draws power from a fuel-burning ICE. The delivery and use of electricity to propel a PHEV for even a portion of its drive cycle uses technologies that are identical to those used by EVs, and this justifies the recognition of PHEVs as a transitional technology to pure EVs.

PHEVs are currently an emerging technology. They are relatively costly and they are heavy because they require two drivetrains: one for electricity and another for an ICE. Less than 8,000 were sold in the U.S. in 2011, compared to total vehicle sales of 12.7 million.[2] All use gasoline as their onboard conventional fuel, although natural gas is a viable alternative that would reduce GHG emissions even further. For example, in 2011, Hyundai Motor Company, South Korea's largest automaker, unveiled the Blue City bus, its first natural gas powered hybrid electric bus. Hyundai is testing 30 Blue City buses in Korea and plans to mass produce the vehicles in 2012.[3] Other fleets of natural gas fueled hybrid electric vehicles can be found elsewhere around the world.

Once electricity is generated onboard FCEVs, the electric drivetrain from the motor to the wheels is identical to EVs. The fuel delivery systems for FCEVs, however, are completely different from EVs. Hydrogen is a gaseous fuel that must be produced, distributed and then stored onboard vehicles as a chemical. PHEVs do not play a transitional role in helping to pave the way for the infrastructure for hydrogen in FCEVs – but NGVs can.

There is a great technical risk associated with limiting support for transitional pathways solely to PHEVs providing electricity by wire, rather than supporting transitional pathways to FCEVs as well. Thus, there is a failure in the advanced technology provisions of the proposed standards to recognize the need to encourage transitional pathways for FCEVs through support for NGVs, as they do for PHEVs as a pathway to EVs.

This is a critical breakdown in the proposed standards. In their current form, the proposed standards will handcuff FCEV development in favor of EVs. It is far too early, and perhaps inappropriate under any circumstances, for government to be declaring winners in the advanced automotive technology arena.

EV development is currently proceeding more quickly than FCEV development, but a decade ago, this was not the case. Then, the first wave of EV development was collapsing as early EV models failed to meet market expectations, but there was widespread support for FCEVs. In retrospect, it is obvious that the battery technology of that era was not capable of supporting EV requirements. New batteries, redesigned small EV configurations and the advent of transitional PHEV models are now propelling a reemergence of EVs.

The collapse of the earlier generation of EVs propelled FCEV research and development (R&D). A major international effort was launched in the mid-1990s. Thousands of FCEVs were built and have been tested in real world applications and this support from major global automakers continues to this day. Most recently, Toyota Motor Corporation featured a new FCEV, called the FCEV-R, at the 42nd Tokyo Motor Show held in December 2011. Toyota plans a market launch for the FCEV-R around 2015.[4]

Several other major global automakers—including Daimler, Honda and General Motors—have aggressive programs in place to develop commercial FCEVs as part of their suite of sustainable vehicles. These automotive contenders are refining their FCEV products before their 2015 target date for commercial launch. According to *Pike Pulse Report: Light-Duty Fuel Cell Vehicles*, a recent report from Pike Research, a market research firm based in Boulder, Colorado, the FCEV market for LDVs is currently ramping up to commercialization.[5] Five automakers, including Toyota, were scored as "contenders." These companies have a solid foundation for growth and long term success, but have not attained a superior position in the market. Daimler attained the highest overall score in the Pike Research report, since it has laid out a clear path to producing a commercially viable FCEV. Other contributing factors include its strong relationships with infrastructure and government partners and its recent announcement to partner with Linde on infrastructure development. Honda, Toyota and Hyundai-Kia are clustered very close together, and not far below Daimler. Honda is the runner-up, based on the high quality execution of its FCEV, the Clarity, its efforts to lay the groundwork for a commercial launch and its continued public commitment to FCEV commercialization.

The final contender, General Motors (GM), has made a strong commitment to FCEV commercialization and has excellent fundamentals for entering this market successfully. GM has invested more than $1.5 billion into fuel cell transportation technologies in the last 15 years and is developing a production fuel cell system that could be ready for commercialization in vehicles in 2015. Currently, its fleet of Chevrolet FCEVs are part of Project Driveway, the world's largest demonstration of FCEVs, which have amassed nearly 1.4 million miles of real world driving by thousands of people since 2007.[6]

A second Pike Research analysis in 2011, the *Fuel Cells Annual Report*, notes that adoption of fuel cell powered products is gathering momentum in a wide variety of applications, including transportation. Global fuel cell shipments doubled between 2008 and 2010, from approximately 7,500 units to more than 15,000 units annually. During that time, the fuel cell industry experienced a compound average annual growth rate of roughly 27 percent. Although shipments in the transportation sector remain small, significant volumes for fuel cells in cars and buses were predicted to grow as automakers gear up for FCEV launches around 2015.[7]

Meanwhile, another market research firm, The Freedonia Group, Inc., based in Cleveland, Ohio, has predicted in *World Fuel Cells* that commercial demand for fuel cell products and services will more than triple to $2.85 billion in 2015 and then triple again to $9.3 billion in 2020. Although fuel cells used in motor vehicles will account for only 0.5 percent of the total number of systems sold in 2020, they will make up the largest single share of demand in dollar terms.[8]

The U.S. National Hydrogen Association, then the name of the major hydrogen trade association headquartered in Washington, DC, released a report in 2010, *Hydrogen and Fuel Cells: The U.S. Market Report*, which identified 212 hydrogen powered LDVs traveling on U.S. roads by the end of 2008. Together, they had been driven a total of 1.1 million miles. They included 22 ICE powered vehicles and 190 FCEVs. There were also 450 hydrogen fuel cell powered forklift trucks in operation at industrial sites in the U.S. Vehicles were currently in operation or planned for operation at 33 sites in 16 states.[9]

A mature industry exists globally to produce hydrogen, although most hydrogen is currently used to upgrade petroleum products or as a chemical feedstock, rather than directly as a transportation fuel. More than 40 million tons of hydrogen are produced globally, which is about 1 percent of total global energy production. More than 10 million tons of hydrogen are produced in the U.S, which is enough to fuel 35 million FCEVs, or more than 10 percent of the LDV fleet.[10]

NGVs as Transitional to FCEVs

In 1989, Energy Futures, Inc. completed its first analysis of the opportunities for deploying alternative fuel vehicles in the U.S. The resulting book, *Drive for Clean Air*, was one of the first to declare natural gas as a preferred alternative transportation fuel, based on a range of policy grounds, over methanol, then the option favored by many government energy agencies in the U.S.[11] Since then, methanol vehicles have virtually disappeared, a number of other alternative fuels have come and gone, and the current portfolio of energy options has broadened to include a wider range of alternative fuels than ever before.

One of the constants in this period of turmoil, however, has been natural gas. The population of NGVs on U.S. roads has roughly tripled since 1989 to over 114,000 on the roads in 2009, according to the U.S. Energy Information Administration (EIA).[12] According to the International Association for Natural Gas Vehicles (IANGV) market survey presented at the 12th World IANGV Conference and Exhibition held in Rome, Italy, in 2010, the number of NGVs worldwide grew from 2.8 million in 2003 to 11.4 million in 2010.[13] It claims the total now exceeds 13 million. NGVs are on the roadways in more than 80 countries around the world.

Another 2011 market survey from Pike Research predicts that worldwide NGV sales will increase at a healthy pace over the next several years, rising from 1.9 million vehicles per year in 2010 to more than 3.2 million NGVs annually by 2016, presenting a 7.9 percent compound annual growth rate (CAGR). The number of refueling stations will increase from approximately 18,000 in 2010 to just fewer than 26,000 in 2016, which is a 5.9 percent CAGR.[14]

The growing fleet of NGVs in the U.S. is a major contributor to the climate and energy policy goals of the proposed standards. This is properly reflected in the proposed methodology for determining CO_2 levels for PHEVs and dual fuel compressed natural gas (CNG) vehicles based on the recognition that it is very likely that the consumer will seek to use cheaper electricity and natural gas fuel as much as possible.

Arguably, however, the most important long term contribution of NGVs is their role as a transition to FCEVs. Natural gas is the feedstock used to produce more than 95 percent of the hydrogen on the U.S. market today.[15] Increased U.S. natural gas production to serve transportation markets directly to power NGVs or indirectly as a feedstock for hydrogen would create jobs in the U.S., while decreasing the demand for imported oil. A 2 percent increase in U.S. natural gas production would provide enough feedstock for hydrogen production to support 10 million FCEVs[16] As discussed in more detail in the next section, the technologies used to transport, store, dispense and burn natural gas are directly analogous to the systems used for hydrogen.

Thus, the role of natural gas in helping to establish the ultimate availability of hydrogen as part of a sustainable transportation system provides a critical policy rationale to justify investment in a major NGV market and the infrastructure to support it. There are technology and infrastructure synergies between NGVs and hydrogen FCEVs. In many ways, promotion of natural gas use in NGVs can facilitate the eventual transition to a hydrogen transportation economy.

Energy Futures, Inc. was one of the early voices linking NGVs as a transition to the hydrogen economy. Its 1992 book, *Paving the Way to Natural Gas Vehicles*, noted that:

> …natural gas vehicles may be vital to the successful transition to hydrogen fuel. Because natural gas vehicle technology is more advanced than hydrogen fuel technology, use of natural gas vehicles will help establish the infrastructure and technology necessary for ultimate utilization of hydrogen.[17]

Since then, nearly all NGV trade associations have endorsed the role of natural gas in facilitating a transition to hydrogen FCEVs. These include the International Association for Natural Gas Vehicles, NGV America in the U.S. and the European Natural Gas Vehicle Association. There are ample and growing supplies of natural gas in the U.S. Increased use of domestic natural gas has become a cornerstone of the U.S. energy policy enunciated by President Obama in his January 24, 2012, State-of-the-Union address to Congress and the American people. The logic of increased use of natural gas as a component of a transitional strategy to FCEVs has, in fact, long been recognized by many U.S. government agencies and by leading energy policy agencies internationally.

Synergies between Natural Gas and Hydrogen

The synergies between NGVs and hydrogen FCEVs have been identified in a number of Energy Futures publications, most notably in its third transportation energy policy book, *Harnessing Hydrogen: The Key to Sustainable Transportation*.[18] The six critical components of the transportation fuel cycle that exhibit compelling synergies between natural gas and hydrogen are as follows:

- Natural gas is the preferred feedstock for hydrogen production
- NGV stations are ideal locations for hydrogen production and dispensing
- The key distribution and storage technologies for the fuels are similar
- Mixtures of natural gas and hydrogen are viable fuels
- Onboard fuel storage and management technologies are analogous
- Safety standards and training programs for hydrogen can be derived from natural gas

Natural gas is the preferred feedstock for hydrogen production

Today, almost all hydrogen is produced from fossil fuels. Globally, about 48 percent of the hydrogen is obtained from natural gas as a feedstock, but in the U.S., natural gas accounts for a far greater share, over 95 percent.[19] Although it can be produced from a variety of renewable resources through electrolysis and a number of thermal or chemical conversion processes, none of these are economically viable. Thus, the transition to renewable hydrogen is not yet commercially feasible and it is likely that natural gas will be the primary hydrogen feedstock for decades to come.

The U.S. National Hydrogen Association 2010 report, *Hydrogen and Fuel Cells: The U.S. Market Report*, estimates that more than 10 million tons of hydrogen were produced in the U.S. in 2008. Only a small portion was used in transportation; most was used as a chemical feedstock or as a feedstock to upgrade petroleum fuels. Of the amount used as a transportation fuel, approximately 90 percent was used as onboard compressed gaseous hydrogen, while the other 10 percent was stored onboard as liquid hydrogen. Likewise, approximately 90 percent of hydrogen vehicles were powered by fuel cells and the other 10 percent were powered by ICEs.[20]

Hydrogen can be produced from methane in natural gas using high temperature and pressure steam. This process, called steam methane reforming, is a mature technology, widely used commercially around the world to produce hydrogen efficiently, cleanly and cheaply. Another option is partial oxidation, which can include gasification of solid or liquid feedstocks.

Several years ago, the $1.2 billion DOE Hydrogen Fuel Initiative led a comprehensive R&D program to overcome the barriers to even lower cost hydrogen production from natural gas. It projected a cost of $3.60 per gasoline gallon equivalent[21] (gge) for hydrogen produced from natural gas at a centralized production facility, delivered, and untaxed, while coproducing electricity at $.08 per kilowatt hour (kWh). This was down from about $5.00 per gge prior to 2003. The hydrogen production cost goal is $2.00 to $3.00 per gge, which the DOE expects to be competitive with the cost of gasoline in 2015.[22]

Researchers at the Center for Transportation Research at Argonne National Laboratory (ANL) in Illinois have completed a detailed market assessment of four scenarios for the introduction of NGVs and FCEVs powered by hydrogen produced from natural gas into the U.S. motor vehicle fleet.[23] The study sought to identify the oil displacement that can be secured over the next several decades by sustained transportation sector use of natural gas either directly as CNG in NGVs or indirectly as compressed hydrogen in FCEVs. Four scenario pathways differed with respect to the degree of success anticipated for natural gas in transportation. The scenario most favorable to hydrogen envisioned producing hydrogen from natural gas for use in FCEVs. It was found to be capable of displacing up to 23 quadrillion Btu of transportation oil consumption by the year 2050, which is **roughly two-thirds of the total petroleum used in the transportation sector today and could completely eliminate all oil imports.** The analysis concluded that a major introduction of natural gas into the transportation energy sector as a direct vehicular fuel could promote a promising eventual application of natural gas in transportation as a feedstock for hydrogen dispensed as fuel for use in FCEVs.

NGV stations are ideal locations for hydrogen production and dispensing

By the end of 2008, there were only 61 operational public and private hydrogen fueling stations in the U.S. and another 15 in Canada, compared to roughly 150,000 gasoline fueling stations.[24] The future viability of FCEVs hinges on a rapid expansion of the fledgling hydrogen fueling infrastructure. The two approaches are centralized and decentralized. Producing hydrogen centrally in large plants cuts costs per unit of hydrogen, but faces substantial distribution obstacles and costs, particularly while demand for hydrogen vehicle fuel is low. Producing hydrogen near the point of end use—at fueling stations, for example—cuts distribution difficulties and costs, but can present challenges at the decentralized point of production. The best strategy is to exploit the synergies between the uses and use the existing and growing network of NGV refueling stations as the place to build decentralized hydrogen production and fueling systems.

An existing natural gas fueling facility is ideal for use as the base for a decentralized hydrogen production and fueling infrastructure for several reasons. First, the natural gas that is already delivered to the NGV fueling station can provide the feedstock for the production of hydrogen. Second, it can serve as a platform upon which to build future hydrogen dispensing sites. Third, it can provide access to potential early adopters of first generation hydrogen vehicle technology. Fourth, it creates the possibility for NGV fueling station operators to offer a premium, lower emission grade of fuel containing mixtures of natural gas and hydrogen.

Small-scale fuel processors that produce hydrogen from natural gas at NGV fueling stations could prove to be the critical element in a viable fuel cell power generation system. Researchers at H2fuel and Argonne National Laboratory (ANL) have worked on a project to develop a compact and efficient natural gas fuel processor for applications at NGV refueling stations. The reformer unit converted natural gas with the help of a novel membrane developed at the University of Kentucky. Thermal efficiencies for the fuel processor operations were calculated to be in the range of 78 to 84 percent.[25]

In view of the similarities between infrastructure issues facing natural gas and hydrogen, the DOE in 2002 selected the Gas Technology Institute (GTI) to head a $4.2 million contract to develop a prototype commercial hydrogen fueling station based on steam reforming of natural gas. The system includes a high efficiency fuel reformer, an appliance quality hydrogen compressor, a hydrogen purification system and an advanced fuel dispenser modeled on technology used to dispense compressed natural gas (CNG). An economic analysis concluded that the decentralized production of hydrogen at natural gas fueling stations would cost between $3.50 and $4.00 per gge of hydrogen.[26]

A 2008 white paper by General Motors estimated the delivered cost of hydrogen produced by steam reforming of natural gas occurring at a fueling station in a distributed production scenario to be $3.10 per gge. This is close to the actual price of a gallon of gasoline per mile of travel by a conventional vehicle. Moreover, the GM analysis predicted the delivered cost of hydrogen produced from natural gas will drop to $2.00 per gge by 2015, while most oil price scenarios predict increasing gasoline and diesel fuel prices.[27]

ChevronTexaco, the second largest energy company in the U.S. and the fifth largest in the world, has been one of the most active major oil companies building hydrogen fueling stations in the U.S. using natural gas as the feedstock. Many of its stations have been managed by Chevron Energy Solutions, a major provider of energy services and energy project management to public institutions. ChevronTexaco Technology Ventures, LLC has provided technical expertise and operational guidance for the energy station using their staff of experienced engineers and scientists from their hydrogen business unit.[28]

The optimization of compressed hydrogen fueling methodologies is important for managing safety, range and public acceptance of this emerging vehicle fuel option. A team of researchers at Chrysler has studied past hydrogen fueling station demonstration projects to gain insight into approaches to controlling temperature fluxes during vehicle refueling. Their analysis concluded that natural gas has set the precedents for hydrogen vehicle fueling. It noted that hydrogen fueling technology has been demonstrated for more than 20 years, but its development has been largely evolutionary in nature and based in part on longstanding NGV fueling technologies and practices.[29]

Another study by researchers at the Pembina Institute in Canada and the Stockholm Environment Institute, the Tellus Institute and the University of California Berkeley campus in the U.S. included a detailed scenario analysis of a large scale transition to hydrogen. The results indicated that significant reductions of GHG emissions can be achieved. Total hydrogen demand by 2050 is estimated to reach between 120 and 190 million metric tons, depending on the scenario, which would be more than a tenfold increase over current levels. About 70 percent of this demand would be accounted for by more than 100 million light duty FCEVs. In the early years of the transition, all hydrogen supply would be produced onsite, mainly at NGV fueling stations. By 2050, about 80 percent of hydrogen supply would transfer to large central production sites and be delivered through pipelines to metropolitan areas. Nearly 650,000 miles of new pipeline, 1,800 central production facilities and 40,000 onsite units would be needed. By 2050, delivered costs of hydrogen converge to around $2.30 per gge.[30]

Once the technical and economic feasibility of converting natural gas to hydrogen at NGV fueling stations is verified, the next step is to deploy this technology in real world applications. In 2009, the National Renewable Energy Laboratory (NREL), a division of the DOE, contracted with Gladstein, Neandross & Associates, a consulting company based in Santa Monica, California, to survey opportunities to integrate hydrogen into the natural gas vehicles and fueling stations of the Interstate Clean Transportation Corridor (ICTC), a network that now includes over 600 heavy duty trucks and 20 fueling stations in California and Nevada that are fueled by LNG.[31] In a speech on January 26, 2012, President Obama praised the ICTC project as a prime example of U.S. companies using domestic clean energy to accelerate job creation, incorporate technological innovation, and stimulate environmental and economic benefits at home.[32]

The goal of the study was to lay the groundwork for hydrogen fueling infrastructure along the existing natural gas ICTC to facilitate the introduction and commercialization of hydrogen vehicles along this route. It evaluated whether the existing vehicle stock and fueling infrastructure of the ICTC can help form the foundation for the development of the hydrogen highway. The final report, *Strategy for the Integration of Hydrogen as a Vehicle Fuel into the Existing Natural Gas Vehicle Fueling Infrastructure of the Interstate Clean Transportation Corridor Project,* explored the potential for piggy-backing early hydrogen production, dispensing and consumption onto the already successfully deployed NGV projects pioneered by the ICTC. In addition, the report made recommendations for five specific demonstration projects that are best suited for the development of hydrogen infrastructure.

In 2004, the DOE released a design report for a combined hydrogen and compressed natural gas fueling station called the APS Alternative Fuel Pilot Plant. Due to the limited construction standards, the hydrogen fueling station was designed based on existing natural gas standards. In addition to producing hydrogen, the plant was designed to deliver CNG for use as a motor fuel.[33] Shortly thereafter, the pilot plant opened in Phoenix, Arizona. It produces and compresses hydrogen on site through an electrolysis process. The pilot plant also compresses natural gas on site and includes natural gas and hydrogen fuel dispensers and a credit card billing system. The compressed hydrogen is ultimately used to fuel ICE vehicles that operate on 100 percent hydrogen or blends of 15 to 30 percent hydrogen and CNG at pressures up to 5,000 pounds per square inch (psi). Both hydrogen and CNG motor fuel dispensing is performed in the same manner, using different dispensers. One dispenser is used for hydrogen and hydrogen blended HCNG. A second dispenser provides only CNG. The hydrogen dispenser is a dual station, with one hose dispensing 100 percent hydrogen into a vehicle at up to 5,000 psi and the other hose dispensing fuel blends at pressures up to 3,600 psi.[34]

The South Coast Air Quality Management District (SCAQMD) in Los Angeles maintains a strong commitment to the transition to hydrogen FCEVs and has financed the construction of a number of hydrogen refueling stations along the ICTC. It has identified the use of hydrogen fueled vehicles as a key air quality attainment strategy for the Los Angeles region. In September 2002, the SCAQMD approved an initial network of compressed hydrogen fueling stations for the early surge of prototype FCEVs expected to be introduced by major auto manufacturers.[35] Moreover, the stations in the Los Angeles are the centerpiece of the statewide California Hydrogen Highway, which currently includes 26 hydrogen fueling stations throughout the state.[36]

Obtaining a plethora of construction and operating permits from government regulatory agencies to build new fueling stations can be a long process that occasionally has hampered the growth of an NGV fueling network. Consistent national codes, standards and “best” practices manuals would greatly assist the NGV industry. Uniform national codes and standards could then be easily developed for the construction of integrated natural gas and hydrogen fueling stations, an action that has not yet been undertaken by the federal government.

The key distribution and storage for the two fuels are similar

If produced from natural gas at centralized production plants, hydrogen must be transported to its market and stored until needed. The most common transport pathways for both fuels are pipelines for long distance and trucks for short distances. According to the DOE Alternative Fuel Data Center, most hydrogen used in the U.S. is produced at or very near where it is used, typically at large industrial sites. The nationwide network for longer distance hydrogen distribution includes pipelines and trucks, with several technologies used to store hydrogen at either end of the distribution chain.[37]

Pipelines: This method to deliver large volumes of hydrogen is currently limited, with only about 700 miles of pipelines in the U.S. located near large petroleum refineries and chemical plants in Illinois, California and the Gulf Coast. Pipelines offer the cheapest and easiest mode of long distance distribution of both natural gas and hydrogen. In fact, fuel mixtures of natural gas and up to 20 percent hydrogen can be transported in the more than 1.2 million miles of existing U.S. natural gas pipelines without any modification. Moving higher concentrations of hydrogen requires either pipeline modifications or the construction of dedicated pipelines.

GM is conducting a project in Hawaii with The Gas Company, Hawaii’s major natural gas provider, to use hydrogen mixed with natural gas in the state’s most populated island of Oahu. The Gas Company already produces hydrogen along with synthetic natural gas and delivers it in its pipeline gas stream. Its pipeline gas now contains more than 5 percent hydrogen.[38]

Some modifications to natural gas pipelines are needed if the concentration of hydrogen in the fuel mixture exceeds about 30 percent. Exposure to higher levels of hydrogen, including pure hydrogen, leads to a gradual embrittlement of the steel used in most natural gas pipelines. In order to avoid embrittlement, it is necessary to use different materials, such as stainless steel, or to liner noncompatible pipelines with protective inserts made of hydrogen compatible materials. The alternative is to build dedicated hydrogen pipelines. There are more than 1,000 miles of dedicated hydrogen pipelines in the world today, built serving oil refineries. One U.S. company, Air Products and Chemicals, Inc., alone operates 340 miles of hydrogen pipeline systems.[39] Hydrogen pipelines are more costly to build than modified natural gas pipelines, but there are still synergies between the two fuels because new hydrogen pipelines could be sited along existing natural gas pipeline rights-of-way.

Trucks: Heavy duty trucks especially designed to carry CNG or liquefied natural gas (LNG) are commonly used to deliver natural gas to remote NGV fueling stations. High pressure tube trailers transport compressed hydrogen gas by truck, railcar, ship or barge but this is expensive and used primarily for distances of 200 miles or less. Liquefied hydrogen tankers filled with cryogenic liquefied hydrogen can transport hydrogen more efficiently over longer distances compared with using tube trailers, even though the liquefaction process is expensive. Most of the hydrogen used in the U.S. space program since the 1960s has been transported in liquefied form by truck. Specially designed transoceanic ships transport cryogenic liquid natural gas and hydrogen around the worth. Although these ships are very expensive, the cost per unit of fuel is quite low.

Some natural gas delivery schemes are modeled after the “mother-daughter” distribution framework widely used in Italy, the first country is deploy large numbers of NGVs after World War II. In this scheme, pipelines are used to deliver large amounts of natural gas to select NGV fueling stations, where a large portion of the delivered gas is offloaded onto trucks for delivery to smaller NGV fueling locations.

Storage: The storage of natural gas and hydrogen is a critical component of these fuel systems during transport on trucks or ships, at fuel dispensing sites and onboard NGVs and FCEVs. The goal in both cases is to provide safe, lightweight and high energy density storage. The technologies in most common use for each fuel are analogous and include the following:

- Advanced lightweight compressed gas storage system in metal or composite tanks is the most common storage option for both fuels. Natural gas is typically stored at pressures between 3,000 and 5,000 pounds per square inch (psi), while the pressures in hydrogen tanks range up to 10,000 psi.

- Natural gas liquefies at -260^{o}F, where its volume shrinks to 1/600th the volume of natural gas in the gaseous state under ambient conditions. Hydrogen liquefies at a much colder temperature, -423^{o}F, which only a few degrees above absolute zero. There are many overlaps between the cryogenic technologies used to liquefy and handle each fuel.

- Advanced adsorption technologies such as metal organic frameworks are being developed for both fuels. Today, natural gas is most commonly stored using carbon based adsorption materials, while hydrogen is generally adsorbed on metal hydride materials.

Mixtures of natural gas and hydrogen are viable fuels

Until dedicated hydrogen FCEVs are more economically feasible and widely available, there is an alternative to pure hydrogen powered vehicles. Mixtures of natural gas and up to 20 percent hydrogen can be burned in conventional natural gas engines without significant engine modifications and without damaging engine performance. Use of fuel mixtures provides an opportunity to begin introducing hydrogen as a transportation fuel through an expanding NGV market. This is an important step in the transition to FCEVs. Additional benefits would include a further reduction in several key automotive air pollutants and improved NGV performance.

Small amounts of hydrogen added to natural gas improve the combustion process of the fuel mixture, which can lead to the development of new ICEs with higher performance capabilities and lower environmental impacts. The improvement results largely from the lean burn property of hydrogen, which allows it to burn at equivalence ratios much lower than those required by natural gas. This property leads to lower fuel consumption without sacrificing engine performance.

The use of fuel mixtures containing between 10 and 30 percent hydrogen by volume offers the opportunity to exploit the positive aspects related to the hydrogen without substantial modification of already existing natural gas engines, avoiding the drawbacks of the use of pure hydrogen in the process. Fuel mixtures result in a new alternative transportation fuel with properties superior to either of its constituents. Premium grades of CNG containing hydrogen can be marketed as premium, less polluting fuel grades at NGV fueling stations, similar to the marketing of middle and high test grades of gasoline today, thereby creating a new business opportunity for the sale of “green” high performance CNG fuel.

Research conducted at the University of Alberta in Canada, has examined fuel mixtures under conditions of varying power and engine speed experienced during typical driving cycles. Tests have been performed using hydrogen fractions of zero (i.e., pure natural gas) and 20, 40 and 60 percent. The goal was to determine the effect of adding hydrogen on the overall fuel consumption and pollutant emissions from a natural gas engine. In one series of tests, the use of varying equivalence ratios decreased CNG fuel consumption by 20 to 27 percent and CO_2 emissions declined between 11 to 19 percent.

Carbon monoxide emissions dropped as much as 97 percent and nitrogen oxide emissions decreased between 31 and 81 percent. On the other hand, hydrocarbon emissions increased between 5 and 42 percent.[40] Another study performed at the University of Calgary, also in Canada, found that the spark timing must be retarded at high engine compression ratios, but if this is done, it is possible to optimize the knock free performance of an engine burning mixtures of natural gas and hydrogen.[41]

Researchers at the Graz University of Technology and the Hydrogen Center Austria have collaborated on a project to modify a dual fuel gasoline/natural gas engine to burn hydrogen blended into the natural gas. Proper adjustment of the electronic control unit was found to allow stable, controlled hydrogen mixing with natural gas across the entire map without compromising the ability to burn gasoline.[42] Researchers at the Istituto Motori, the Italian National Research Council, have assessed the effects of natural gas/ hydrogen blends on the performance of a turbocharged natural gas ICE. No losses in energy efficiency were observed, but significant reductions in CO_2 emissions were seen as the hydrogen component increased. The researchers concluded that dual fuel technology that injects natural gas into an ICE with hydrogen has the potential to achieve cleaner exhaust emissions.[43]

Engineers at the University of British Columbia and Westport Innovations, Inc. in Vancouver, British Columbia, Canada, have tested natural gas and two mixtures of natural gas and hydrogen in a high pressure, direct injection natural gas engine. In the tests, the impact of 23 percent hydrogen blends on emissions was dramatic. Hydrocarbon emissions fell by two-thirds, particulate matter emissions were cut in half and CO_2 emissions fell by more than 20 percent from the already low levels when burning pure CNG. Emissions of nitrogen oxide remained unchanged with the fuel mixture compared to pure CNG.[44]

Onboard fuel storage and management technologies are analogous

Onboard fuel management equipment for both natural gas and hydrogen includes analogous compressed gas piping, compressor regulators and, if the vehicle is powered by an ICE, gaseous fuel injection systems. Several U.S. companies have successfully adapted their line of NGV equipment to handle hydrogen fuel management. For example, Quantum Technologies Worldwide, Inc., based in Irvine, California, has broadened its historical business of supplying technology for natural gas fuel management over the past decade into hydrogen and electric vehicle programs. It now supplies tanks for pure hydrogen and for mixtures of hydrogen and natural gas fuel and is also involved in a number of cutting edge projects to develop commercially viable PHEVs and FCEVs. About a decade ago General Motors acquired a significant equity interest in Quantum.[45]

Ford Motor Company has been developing a hydrogen powered ICE for more than a decade with the view that hydrogen ICEs provide a viable bridge from vehicles powered by gasoline ICEs to fuel cell vehicles powered with hydrogen. Toward that end, the company has redesigned a 6.8 liter, V-10 Triton ICE to run on pure hydrogen and to power an E-450 shuttle bus. The fuel delivery system needed to be completely replaced to accommodate compressed hydrogen gas. The system was similar to the one developed by Ford for CNG vehicles. Unlike gasoline and natural gas, however, hydrogen offers no lubricity because of its purity. As a result, the internal wear components needed upgrades to provide durability over 150,000 miles of engine operation. The E450 hydrogen vans have been deployed in a number of fleets around the U.S. Tests have shown energy efficiency of the hydrogen engine to be 29 percent, a 12 percent improvement over the 26 percent for the gasoline ICE.[46]

For more than a decade, Cummins Westport Inc., and its joint venture partners, Cummins Inc. of Columbus, Indiana, and Westport Innovations Inc. of Vancouver, British Columbia, Canada, have developed and marketed a wide range of advanced natural gas engines. One of its projects has conducted a field trial using a blend of natural gas and hydrogen in a bus engine operated by SunLine Transit Agency of Thousand Palms, California. NREL and California's SCAQMD each provided funds for the project. The goal of the project was to verify that hydrogen/natural gas fuel blends can be used under normal work conditions while reducing pollution, including greenhouse gas emissions, and increasing fuel economy. The Cummins Westport 5.9-liter B Gas Plus engine, an advanced 230 horsepower natural gas engine, was the test engine. Previous tests have shown that a mixture of 20 percent hydrogen and 80 percent natural gas can be burned in unmodified natural gas engines without affecting engine performance and efficiency.[47]

Safety standards and training programs for hydrogen can be derived from CNG

The safety record of NGVs has proven to be superior to the record for conventional petroleum powered vehicles. The first NGV safety “incident” was not reported until 1984, even though the industry was launched in the World War II era. After hundreds of millions of miles driven on U.S. roads, NGVs have proven to be a safe alternative to conventional gasoline cars. Maintaining this record of excellence is critical to consumer acceptance of NGVs.

A similar comprehensive set of safety codes and regulations are needed for hydrogen fuel systems in order to ensure a comparable or better safety record during a transition to hydrogen FCEVs. Creation of these standards is a daunting task that has attracted the attention of safety agencies around the world. The hydrogen industry would be well-served by a set of uniform national safety codes and standards for motor vehicle operation and refueling.

The usual starting point for new hydrogen regulations is the existing codes and standards that have been developed in recent decades during the market growth of NGVs. For example, the European Integrated Hydrogen Project (EIHP) worked for several years to develop draft regulations for hydrogen vehicles to European Commission. The EIHP project began in February 1998. The framework for the draft regulations for hydrogen vehicles was based on the draft European Commission regulation for CNG vehicles.[48]

Researchers at the Japan Automobile Research Institute have studied hydrogen accumulation during leaks and dispersion following the elimination of the leaks as part of the development process for standards affecting the FCEV industry. One study compared the patterns of hydrogen leaks onboard vehicles were compared to the results of leaks of methane, the key component in natural gas. The tests confirmed the adequacy of the standards for hydrogen vehicle safety set in Japan because the risks paralleled those in NGVs, which have a long record of safe operation in Japan.[49]

For more than a decade, the DOE has coordinated the efforts of codes and standards organizations to develop new, more appropriate codes and standards that will ensure the safe use of hydrogen for transportation and stationary applications in the U.S. It has published a *Hydrogen and Fuel Cells Permitting Guide* and maintains a hydrogen/fuel cell codes and standards website that provides information on worldwide development of hydrogen codes and standards.[50]

A key component of hydrogen safety is the existence of trained automotive maintenance and repair professionals that are capable of inspecting and, when necessary, repairing hydrogen infrastructure equipment and hydrogen powered conventional vehicles and FCEVs. A similar challenge existed for the NGV industry as the numbers of NGVs on U.S. roads began to increase over the past few decades. The NGV industry addressed this concern by creating new training programs focused on transferring the skills needed to properly maintain NGVs, which can be used as a model for analogous programs for FCVs.

For example, Natural Gas Vehicle Institute, based in Las Vegas, Nevada, is North America's leading provider of training and consulting on natural gas as a transportation fuel. It offers technical consulting services on the design of safe CNG fueling stations, assistance for NGV fleets operators, CNG fueling station problem troubleshooting and NGV maintenance facilities upgrades. It also sponsors technical training courses addressing CNG fuel system safety, NGV driver and mechanic safety, and CNG fueling station operation and maintenance.[51] Moreover, the Natural Gas Vehicle Technology Forum has been created by the DOE and the California Energy Commission to unite a diverse group of stakeholders to identify natural gas engine, vehicle and infrastructure technology targets and to communicate high priority needs of NGV end users to equipment and vehicle manufacturers.[52]

Recognition of Role of Natural Gas in Transition to Hydrogen

Widespread interest in FCEVs as the transportation technology of the future emerged in the early 1990s when the earliest prototype cars appeared at auto shows and hydrogen conferences around the world. These early developments were tracked in the 1995 Energy Futures book, *Harnessing Hydrogen: The Key to Sustainable Transportation*.[53] Concurrently with the advent of new FCEV technology was an emerging focus in energy policy analyses of the potentially positive role natural gas and NGVs could play in the transition to a hydrogen FCEV economy. Linking NGV and FCEV development is a well-studied and understood energy policy. Several leading government energy agencies actively involved in this field are discussed briefly below. Their work has been cited and footnoted earlier in this report.

U.S. Department of Energy (DOE)

In the U.S., the DOE has conducted a hydrogen research and development program since the early 1970s. This effort grew to become a world-leading energy program in the 1990s and 2000s, although it has been scaled back in recent years in favor of PHEV and EV programs. Even so, the DOE has a long history addressing the challenges of producing low-cost hydrogen, storing it at an acceptable energy density and converting it to useful work in a device that has a high efficiency. In 1990 and 1996, federal legislation was enacted by the U.S. Congress enabling the DOE to expand its activities. The National Hydrogen Program, which continues today, focuses on exploration of long term, high risk concepts to address hydrogen as an alternative energy form.

The DOE maintains several websites devoted to hydrogen and FCEVs, including a site maintained by the Alternative Fuel Data Center at NREL. To cite a few examples of DOE projects that have analyzed natural gas as a bridge to hydrogen, NREL published a report of the findings of a DOE workshop called the *Blueprint for Hydrogen Fuel Infrastructure Development*.[54] In 2003, the DOE released a new planning document, the *National Hydrogen Energy Roadmap*, which shaped many of the agency's priorities and programs with regard to hydrogen energy and fuel cell vehicle development. The roadmap outlined key issues and challenges in hydrogen energy development, including the need to exploit the natural gas/hydrogen connection, and suggested paths that government and industry could take to expand use of hydrogen energy.[55] In January 2009, the DOE released a progress report, *Hydrogen and Fuel Cell Activities, Progress, and Plans: Report to Congress*, which discusses the current status of the hydrogen program.[56]

Nearly all of the national research laboratories managed by the DOE have conducted extensive research into hydrogen energy systems. Two of them, Argonne National Lab (ANL) in Illinois and the National Renewable Energy Laboratory (NREL) in Golden, Colorado, have been particularly focused on natural gas/hydrogen synergies. ANL researchers produced the *A Full Fuel Cycle Analysis of Energy and Emissions Impacts of Transportation Fuels Produced from Natural Gas* study and developed the Hydrogen Delivery Scenario Analysis Model (HDSAM). NREL is the home of the Alternative Fuel Data Center. NREL has also produced the *Strategy for the Integration of Hydrogen as a Vehicle Fuel into the Existing Natural Gas Vehicle Fueling Infrastructure of the Interstate Clean Transportation Corridor Project* and many other reports.

The Energy Information Administration (EIA), another arm of the DOE, has also studied a range of hydrogen transition issues. In 2008, it studied the impacts of the commercialization of advanced hydrogen and fuel cell technologies in the transportation and distributed generation markets in a report, *Hydrogen Use, Petroleum Consumption, and Carbon Dioxide Emissions*.[57] The report highlighted the role of natural gas as a bridge fuel that might provide some initial penetration that could lead to more experience with hydrogen as a fuel and greater public acceptance.

National Research Council

The U.S. National Research Council (NRC), the principal operating arm of the National Academy of Sciences and the National Academy of Engineering, has also been involved in hydrogen policy analysis. At the request of Congress, it has completed several annual reviews of the DOE hydrogen and fuel cell programs. Among the published studies of the NRC was a 394 page report, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*.[58]

The report, sponsored by the DOE, concluded that a transition to hydrogen as a major fuel in the next 50 years could significantly change the U.S. energy economy, reduce air emissions and expand domestic energy resources. If technical problems are solved and technologies reach a mature stage of development, the report concluded that hydrogen could be produced and used in FCEVs at reasonable cost, due to improved efficiencies of fuel cells compared to internal combustion engines. To address the chicken and egg issue, an initial stage where hydrogen is produced on a small scale using natural gas or electricity seemed appropriate to the NRC. For this to happen, production costs for small units must be sharply reduced, which may be possible with expanded research. During this transition, other technologies for producing hydrogen on a larger scale can be developed.

International Energy Agency

The International Energy Agency (IEA), an intergovernmental organization based in Paris, France, has also examined the use of natural gas as a bridge to hydrogen. It has published a report, *The Contribution of Natural Gas Vehicles to Sustainable Transport*, assessing the commercial viability of NGVs in global markets. The IEA concluded that NGVs perform well, particularly in terms of pollutant emissions compared to current diesel vehicles. It recommended tax and subsidy policies to make NGVs sustainable in the long run.[59]

The IEA has also been implementing a Hydrogen Implementing Agreement involving its member countries for more than a decade. Annex 13 under the agreement, Design and Optimization of Integrated Systems, includes a project directed by the U.S. to analyze refueling options for hydrogen vehicles. Three of the six fueling station configurations studied by the IEA involve delivery of hydrogen to the station site. In the other three cases, hydrogen is generated at the site.[60]

Other National Governments

Several other individual countries have heavily promoted hydrogen and fuel cells in recent decades. For most of the past 20 years, the three largest government hydrogen programs have been conducted in the U.S., Europe and Japan. Each country has invested well more than $100 million per year in support of hydrogen projects and policy analysis to facilitate the transition to a hydrogen transportation system. In Japan, the hydrogen program has been coordinated by the New Energy and Industrial Technology Development Organization (NEDO) and the National Institute of Advanced Industrial Science and Technology (AIST). NEDO's Fuel Cell and Hydrogen Technology Department and AIST's Polymer Electrolyte Fuel Cell Cutting-edge Research Center manage progress of important technical aspects of hydrogen powered vehicles.

The European Commission (EC) has coordinated most hydrogen and fuel research activities in Europe. It has financially supported dozens of hydrogen and FCEV research and demonstration projects on the continent. It also published a comprehensive report on the technical and economic status of alternative fuels for road transport in 2004. The report focused on natural gas and hydrogen and proposes measures by which the EC can promote their use. Natural gas was identified as the only alternative fuel with a potential for significant market share well above five percent by 2020, which could potentially compete with conventional fuels in terms of the economics of supply in a mature market scenario.

Conclusions

Government policies, including the proposed standards, will greatly affect the potential of hydrogen to emerge as a viable alternative fuel for FCEVs. Laws, rules and regulations that encourage the development of NGVs and the associated natural gas refueling infrastructure encourage hydrogen and FCEVs and lay the foundation for achieving important emission and oil import reduction objectives. On the other hand, laws, regulations or other government actions that place NGVs at a disadvantage or favor other alternative fuel pathways increase the risk of sapping support that NGVs need to achieve their market and public policy potential. The end result could be that the U.S. transportation system will stagnate, locked into 19^{th} century fuels and 20^{th} century engines that 21^{st} century consumers won’t want to buy.

This report argues that the synergies between natural gas and hydrogen are so pronounced that encouraging natural gas vehicle fuel and NGVs are the necessary and best ways to promote the most rapid and cost effective advent of hydrogen and FCEVs in the U.S. The synergies start with natural gas as the primary and cheapest feedstock for nearly all hydrogen production today and continue through every step in the fuel supply chain, including the combustion behavior of engines.

The role of NGV fueling stations is a particularly critical junction where natural gas and hydrogen synergies most closely coincide. A viable strategy to promote rapid introduction of the hydrogen infrastructure required by FCEVs is to convert natural gas into hydrogen onsite at existing natural gas fueling stations and to deliver it to FCEVs at the same location. This strategy eliminates the need to transport hydrogen long distances from a centralized production facility and it provides a convenient refueling location for FCEV motorists at a fraction of the cost of a dedicated hydrogen fueling station. It also allows for the creation of unique brands of premium natural gas fuels for NGVs containing small percentages of performance-enhancing, pollution-reducing hydrogen.

There are no losers in this approach, but it has been overlooked in the proposed standards by the failure to include NGVs in the advanced technology incentive program as a critical bridging technology to FCEVs. This oversight is made worse by the fact that the proposed standards place PHEVs in the advanced technology incentive program precisely for their role in facilitating the introduction of EVs. Rewarding PHEVs, while ignoring NGVs, creates an unequal playing field and, in essence, picks a winner among the two pathways to electrified vehicles, which, in other words, picks EVs over FCEVs.

Many leading players in transportation technology, including a number of the largest automakers, are actively pursuing development of FCEVs along with their EVs in the belief that it is too early to pick a winner along the path to electrified vehicles. These FCEV programs are significant, well-funded and geared to commercializing FCEVs in the middle of this decade.

California should adopt the same "all of the above" logic for pathways to vehicle electrification. Fortunately, the U.S. government is already a global leader in hydrogen and fuel cell technology. Many of its agencies, most notably the DOE and several of its national laboratories, have been studying hydrogen and fuel cell technologies for decades. The in-house expertise is enormous and the wealth of policy analyses upon which to base a new initiative is vast.

The accumulated work of these and other reputable government agencies instills confidence that revising the proposed standards to provide advanced technology incentives for NGVs as recommended in this report can be quickly and effectively implemented. This would be an important first step. Other recommended steps involve focusing on providing guidelines and incentives to design natural gas fueling stations with the capability of deploying critical components of the hydrogen fueling infrastructure as well. National codes and standards for the construction of joint natural gas and hydrogen fueling stations are needed, and a national program to implement such a joint fueling network is a vital step toward a successful launch of FCEVs into the transportation market.

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Energy Futures, Inc. was founded in 1979 to study energy and related environmental issues in the transportation sector. It has published a number of books, reports and professional papers that examine the introduction of natural gas and hydrogen as transportation fuels and the synergistic relationship between the two fuels. The books include The Drive for Clean Air, Paving the Way to Natural Gas Vehicles, Harnessing Hydrogen: The Key to Sustainable Transportation and The Hydrogen Transition (co-edited). Energy Futures also publishes the quarterly international journal, The Clean Fuels and Electric Vehicles Report, and the bimonthly newsletter Hybrid Vehicles.

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