DOE/GO/10125--T1

FINAL REPORT

DOE COOPERATIVE AGREEMENT NO. DE-FC36-95O10125, A004
Title: DEVELOPMENT OF A PARTNERSHIP WITH GOVERNMENT AND INDUSTRY TO ACCELERATE THE COMMERCIALIZATION OF HYDROGEN
Budget Period - From 09/30/1995 thru 10/31/1996
U.S. Department of Energy
Golden Field Office
1617 Cole Blvd.
Golden, CO 80401

Submitted by: The National Hydrogen Association

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EXECUTIVE SUMMARY

This Final Technical Report provides a summary of the activities performed by the NHA in accordance with the Cooperative Agreement. Activities are broken down by task area, and include the following:

Information Exchange within the NHA, which includes the two NHA newsletters, the *NHA Advocate*, and the *H_2 Digest*, as well as directory information.

Information Exchange within the Hydrogen Industry, which includes conference and meeting attendance, presentations of papers, and HTAP activities.

Information Exchange with Other Critical Industries and the Public, which includes press conferences, and public awareness activities.

Annual U.S. Hydrogen Meeting, NHA's signature event. The 7th Annual U.S. Hydrogen Meeting was held April 2-4, 1996 in Alexandria, Virginia in conjunction with the U.S. DOE's Hydrogen Technical Advisory Panel Meeting and the SAE's Fuel Cell TOPTEC.

Industry Perspective and Needs, which covers activities related to the Hydrogen Industrialization Plan.

Codes and Standards, which includes workshop and workgroup activities, as well as other safety-related activities. The objective of the codes and standards activities is to establish expert working groups to develop industry consensus on safety issues, and develop compatible standards and formats, and product certification protocols.

Information Exchange within the NHA

NHA Advocate

The new quarterly newsletter, the *NHA Advocate,* was developed, including the design, a production schedule, an editorial schedule, and distribution list.

The objective of the newsletter is to help accelerate technology transfer within the hydrogen industry and with DOE by facilitating information exchange on hydrogen technologies and institutional and infrastructure issues critical to the commercial use of hydrogen as an energy source. Most of the recipients of the newsletter would not have obtained the information from other sources. *Advocate* newsletters were distributed in April, July, October, and January. One copy of each is included in Appendix A.

H_2 Digest

A new, bolder look for the *H_2 Digest* has been designed. The NHA has expanded the distribution of the *H_2 Digest* by allowing our members to add up to three additional company associates to the *Digest*'s mailing list. Distribution has increased 45% to 152 copies and growing. The *H_2 Digest* was expanded from eight to twelve pages to accommodate for the increased attention hydrogen received in the news. The November/December, January/February, March/April, May/June, July/August, and September/October issues of the *H_2 Digest* were edited, printed, and mailed to members, subscribers, and DOE officials. Sample copies are included in Appendix B.

Information on hearings, government solicitations, and Congressional action on relevant bills and appropriations were gathered for the first of three issues of the *Legislative Update* which is included in every other issue of the *H_2 Digest.*

Distribution of the *Advocate* and *H_2 Digest* was expanded to include all members of the Hydrogen Technical Advisory Panel.

Directory Information

As part of the NHA Membership Directory update, information was requested in an attempt to increase member participation and information exchange. Members were asked to give the names of up to five people within their organization to receive the *H_2 Digest*, the new quarterly newsletter, and to participate on NHA committees. By expanding the participation of its members, the NHA hopes to keep more people informed about hydrogen activities as well as benefit from their expertise through participation on committees. In addition, information was requested on company homepages. We hyperlinked NHA member homepages with the NHA homepage.

Information Exchange within the Hydrogen Industry

S. Leach attended the Hydrogen Outreach Coordination meeting Monday, November 13, 1995 in Golden, Colorado. This activity presented four tasks; Communications, Market Transformation, Education, and Awareness. Under the Cooperative Agreement, S. Leach has been asked to be the task leader for the Awareness task.

The NHA submitted an abstract and paper to *Hydrogen '96–11th World Hydrogen Energy Conference* which was accepted for presentation. The paper, "Bridge to a Sustainable Hydrogen Energy Future: Reassessing the Transition," was presented by Robert Mauro. A copy is included in Appendix C.

The NHA staff distributed two NASA Technology Briefings on hydrogen fire imager technologies that it has developed to members of the NHA. NASA is seeking to identify industry partners to develop these technologies.

S. Leach and R. Mauro attended the Hydrogen Technical Advisory Panel meeting on April 1-2, 1996. Susan Leach attended the Hydrogen Technical Advisory Panel's Demonstration Subcommittee Meeting. Draft Demonstration Briefs developed under the NREL subcontract with the meeting participants were distributed. She also briefed the group on the demonstration-commercialization project directed by S1153.

Ms. Leach and Mr. Mauro attended the DOE Working Group Meetings and the Hydrogen Program Review Meeting, in which Mr. Mauro was a reviewer, in Miami. Ms. Leach participated in the Utilization Working Group while Mr. Mauro participated in the Systems Analysis Working Group. A "Call for Papers" flyer for the *8th Annual U.S. Hydrogen Meeting* was distributed.

The NHA staff reviewed proposed NHA FY 1997 activities with Jon Hurwitch, DOE Hydrogen Program Outreach leader. Written plans were also submitted, and a status report of FY 1996 activities was prepared and submitted for planning purposes.

R. Mauro and S. Leach attended the HTAP meeting on October 15, 1996 in Denver, Colorado. In the public comments session, R. Mauro briefly outlined an alternative approach to systems analysis for the panel's consideration. The NHA staff coordinated with members to provide copies of the newly signed Public Law, H.R. 4138, the *Hydrogen Future Act*, to attendees and distributed information about the *Hydrogen Future Act*.

Information Exchange with Other Critical Industries and the Public

The NHA participated in a press conference held November 15, 1995 at the National Press Club in Washington, D.C. to announce James Cannon's new book, Harnessing Hydrogen: The Key to Sustainable Transportation.

Susan Leach attended the Hydrogen Outreach Coordination meeting on January 18 at the NREL - DC offices, and presented the summaries of the NHA and Awareness activities, including the documentary (see below) and the museum project.

The Executive Committee of the NHA Board of Directors endorsed and made a financial contribution to support production of a one-hour documentary entitled *CLEAN ENERGY: The Promise of Hydrogen*. A letter asking other NHA members to make contributions was sent out under the Chairman's signature. The documentary, to be produced by *Hydrogen 2000, Inc.*, is one of six public awareness activities being pursued by the DOE Hydrogen Outreach Committee.

The NHA exhibited at the Renewable Energy Expo organized and hosted by the House Renewable Energy Caucus. Materials for the exhibit wall were designed and produced. The objective is to increase awareness about the potential of hydrogen among critical groups. Visitors to the NHA booth included DOE Assistant Secretary Christine Ervin, as well as many staffers from Congress. Dr. Robert Reeves was on hand to explain and demonstrate hydrogen and fuel cell technologies. The exhibit also featured a self- contained fuel cell/hydrogen power system courtesy of Ball Aerospace that provided electricity to run a TV/VCR. The exhibit attracted interest, and many attendees stopped and asked questions.

As part of a screening of the hydrogen documentary, *Element One*, hosted by Congressman Robert Walker on July 31 at the Rayburn House Office Building, the NHA set up an exhibit booth and distributed NHA and member literature. Members literature featured information on available hydrogen technologies, such as hydrogen fueled buses, sensors, and electrolyzers. The exhibit was open to the public.

Ms. Leach chaired Session 73: *Hydrogen Energy Systems* at the 31st Intersociety Energy Conversion Engineering Conference.

An article was written to clear up inaccuracies about hydrogen production and safety depicted in the newly released movie, *Chain Reaction,* and posted on the NHA web site. The article emphasized that while *Chain Reaction* takes creative license with science, the benefits of hydrogen as a nonpolluting, sustainable energy carrier are real.

Susan Leach and Bob Mauro attended "The Future for Alternative Energy" meeting in Reno, Nevada in September 1996. Handout materials were prepared, including a "Call for Papers" for the Annual Meeting. Materials taken for distribution included DOE's *Hydrogen Program Overview,* HTAP's *Green Report,* and the Hydrogen Fuel Fact Sheet.

Annual U.S. Hydrogen Meeting

The Annual U.S. Hydrogen Meeting, NHA's signature event, is recognized worldwide for its importance in bringing together a diverse group with a common interest in hydrogen energy technology. The objective is to promote the exchange of information relevant to the development of the commercial use of hydrogen as an energy source within the hydrogen community. Held each year in the Washington, DC area, the meeting draws high level hydrogen policy decision makers, hydrogen and fuel cell industry leaders, research institutions, academics, policy makers, and press from around the world. The meetings have been sponsored every year by the U.S. Department of Energy and NASA: other sponsors include DOT/FTA, SCAQMD, and EPRI.

Three significant mailings were sent publicizing NHA's *7th Annual U.S. Hydrogen Meeting*: (1) a meeting announcement, "Save-A-Date," designed and mailed to approximately 2,500 companies and individuals; (2) requests for sponsorship for the NHA/SAE cosponsored reception mailed to Sustaining, Industry, and Small Business members (26 members); and, (3) an exhibition announcement and registration mailed to approximately 570 potential exhibitors.

The possibility of hosting the ISO-TC 197 plenary meeting and work groups meeting in conjunction with the Annual Meeting was discussed with Tapan Bose, ISO-TC 197 chairman.

The 7th Annual U.S. Hydrogen Meeting was held April 2-4, 1996 in Alexandria, Virginia in conjunction with the U.S. DOE's Hydrogen Technical Advisory Panel Meeting and the SAE's Fuel Cell TOPTEC. There were 200 in attendance. The meeting featured 40 speakers covering four keynote addresses, four general sessions, and three concurrent sessions. Dr. Allen Hoffman, Acting Deputy Assistant Secretary, Office of Utility Technologies at DOE participated as a session chairman and panelist. Neil Rossmeissl presented DOE's Vision for hydrogen, and Alan Lloyd presented HTAP's recommendations. Several of the Hydrogen Program's research activities were represented as well, including Princeton, the Palm Desert Project, an NREL CRADA with DCH Technology.

The *7th Annual US Hydrogen Meeting Proceedings* were compiled and edited, and distributed to 188 meeting attendees in August 1996. The proceedings are included in Appendix D.

A "Call for Papers" flyer was designed to be distributed at the DOE Hydrogen Program Annual Review Meeting for the *8th Annual U.S. Hydrogen Meeting*.

Planning for the *8th Annual U.S. Hydrogen Meeting* included developing a theme, reviewing abstracts, and developing a preliminary agenda. The call for papers was posted on the NHA Web Site.

Industry Perspective and Needs

The NHA staff and Board Members Sandy Thomas and Jay Laskin met with Dr. Russ Eaton and Neil Rossmeissl on November 28, 1995 at the NHA offices to discuss the industry perspective and needs for research, development, and demonstrations.

The NHA planned a workshop to address the development of a Five-Year Hydrogen Technology Development Plan with the Board of Directors Executive Committee.

A draft agenda was prepared for an Executive Committee Planning Meeting for the Industry Plan Workshop held in June. The agenda was sent to the Chairman of the Board for review and suggestions.

The NHA Executive Committee and staff conducted a meeting June 6 - 7 to develop an approach, an agenda, and plans for the Industry Plan Workshop. An action item list delineating responsibilities and resources for materials for the plan was prepared and distributed. The meeting was hosted by Directed Technologies, Inc.

Work began immediately on the action item list, which included the following: 1) a commercialization strawman, 2) a list of barriers to commercialization, 3) likely first markets, and 4) sources of hydrogen (merchant and by-product) or resources for inexpensive hydrogen production, including "cheap electricity" and readily available renewable resources. Draft documents were completed for presentation at a NHA meeting in Stuttgart.

A meeting with NHA board and honorary members (including HTAP chairman Dr. Alan Lloyd and guest Nick Beck of Natural Resources Canada) was held at the Daimler-Benz headquarters in Stuttgart during a break at *11th World Hydrogen Energy Conference.* Dr. Gerhard Isenberg gave a presentation on the recent reorganization at Daimler-Benz. Dr. Keith Prater, NHA Chairman of the Board, briefed the group on the work done by the Executive Committee on the Industry Plan activity. There was overall approval and buy-in of the direction being taken by the Executive Committee.

Venki Raman, chairman of the subcommittee on NHA Support to DOE and Keith Prater, chairman of the Board, and NHA staff met with Allan Hoffman, Neil Rossmeissl, and Gary Burch of DOE to present the recommendations in the NHA white paper, *National Hydrogen Association Input to the U.S. Department of Energy.* Dr. Prater also briefed DOE on the Industry Plan activities that are underway.

Mr. Mauro and Ms. Leach met with Eric Carlson and Christian Demeter of Antares Group to discuss GIS informational mapping needs to support research for the Industry Plan.

Spreadsheets were developed for entry into GIS informational mapping system to support the Industry Plan; the maps being developed include:

1. Renewable Energy Sites: Counties with biomass, wind, and PV sites
2. Hydrogen Production Sites: Counties with merchant (liquid and gaseous)and by-product H_2 production.

3. Hydrogen Projects: Counties with H_2 Projects
4. Hydrogen Energy Enabling Regulations and Incentives: Counties that are air quality nonattainment areas and states with alternative fuel definitions, including those that specify H_2, state incentives, and utility/private incentives.
5. Renewable Energy and Hydrogen Production Sites: A combination of 1 and 2.
6. Hydrogen Projects and Areas with Enabling Regulations and Incentives: A combination of 3 and 4.

Eighteen members and four HTAP members attended, and addressed the three hydrogen applications in the *Plan*: hydrogen-powered vehicles, stationary utility fuel cells, and remote village renewable hydrogen storage with fuel cells to generate electricity at the *Strategic Planning for the Hydrogen Economy: The Hydrogen Commercialization Plan* Workshop on October 8-9, 1996 in Alexandria, Virginia. This plan is attached as Appendix E.

Codes and Standards

The objective of the codes and standards activities is to establish expert working groups to develop industry consensus on safety issues, and develop compatible standards and formats (e.g., the same couplings for dispensing the same form of fuel) and product certification protocols. The NHA has firmly established two working groups on standards for hydrogen fuel tanks and refueling stations, and is aggressively recruiting for experts for a working group on connectors. These experts from industry and research institutions are donating their time and knowledge to participate in this activity.

The first workshop was held May 30-31, 1996 at the NHA offices. A proceedings was produced in late summer, and the second workshop was conducted in October.

Task leaders of the working groups formed at the May Hydrogen Safety, Codes & Standards Workshop were contacted to plan next year's codes and standards activities and workshops.

A copy of the NGV standards was obtained for planning purposes. NGV standards were reviewed to determine which can be modified to be suitable for hydrogen applications.

A preliminary agenda was drafted for the codes and standards workshop held on May 30-31. The draft was distributed to the NHA Executive Committee and other key hydrogen safety, codes, and standards experts for review.

Materials and presentations from the Workshops were compiled to be included in the Proceedings.

The NHA drafted a white paper on developing a codes and standards coalition as a basis for discussion and development of safety codes and standards reviews. Mr. Mauro held discussions with NHA Board members and Counsel for guidance on how to incorporate codes and standards activities into the NHA program. The draft was distributed to key participants for review.

Mr. Mauro attended the meeting of Working Group 3 of ISO/TC 197 on June 27, 1996 in Stuttgart, Germany. This working group, convened by Addison Bain, reviewed the first working draft of ISO/WD 14687 on Hydrogen Fuel - Product Specification.

Ms. Leach attended the 5th plenary meeting of ISO/TC 197 on June 28, 1996 in Stuttgart, Germany, and served on the drafting committee for the meeting. She announced the USA's intention to formally propose three new work items related to the use of gaseous hydrogen: fuel tanks, fueling stations, and connectors. The technical committee agreed to establish these new working groups upon approval of the work items. Project leaders will be confirmed at the same time the proposals are forwarded to the technical committee for voting.

The Hydrogen Safety Coalition white paper was drafted, edited, and prepared for review by Bill Summers, WSRC; Jim Ohi, NREL; Bill Hoagland, WHA and NREL consultant; and Kevin Knudsen, ETEC.

Bob Mauro contacted ISO to discuss submitting procedures for submitting new work proposals for Hydrogen Containers, Connectors, and Service Stations. The ISO proposal is included in Appendix F.

The NHA conducted its fourth Safety, Codes and Standards Workshop on October 10-11, 1996 in Alexandria, Virginia with 23 attendees, including HTAP member Robert Zalosh. The three work groups, WG1: Connectors, WG2: Containers, and WG3: Service Stations continued development of a draft standard (WG2 and WG3) or work plan (WG1).

In addition to the work group meetings, there were five presentations:

1. Support to Early Demonstration Projects: Manual of Recommended Practices, *Bill Hoagland, William Hoagland & Associates*
2. Formulating Standards: ASME's Approach, *Manuel Gutierrez, ASME Int'l.*
3. National Fire Codes: NFPA Codes, Standards, and Recommended Practices, *Tony O'Neil, NFPA*
4. Experiences in Hydrogen Safety, *Mike Swain, University of Miami*
5. Observations from Invited ASME and NFPA Participants, *Ray Art, ASME.*

The NHA staff edited and sent out for review an insurance questionnaire for hydrogen risks and liabilities to be distributed to NHA members. The responses will be used to devise an approach to engage the insurance industry in a dialogue about the potential market for a hydrogen systems business.

Appendix A

Samples of the *NHA Advocate*

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Appendix B

Samples of the H_2 *Digest*

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Appendix C

"Bridge to a Sustainable Hydrogen Energy Future: Reassessing the Transition"

A Bridge to a Sustainable Hydrogen Energy Future: Reassessing The Transition

National Hydrogen Association, Washington, DC
Robert Mauro, Executive Vice President
Jeffrey A. Serfass, President
Susan Leach, Vice President

Abstract

At the World Hydrogen Energy Conference in 1992, several members of the United States hydrogen community authored a presentation titled, "A Bridge to a Sustainable Hydrogen Energy Future." This presentation outlined a "bridge" or framework for advancing from the current energy mix to a hydrogen energy future over the next 40 years, using natural gas, natural gas pipelines and biomass to effect the transition.

The environment for a hydrogen transition has changed since that presentation and a reexamination of earlier assumptions about the framework is needed. Increasing attention to a wide range of environmental considerations, unanticipated progress in enabling technologies, and a clearer understanding of changing energy costs and infrastructure options warrant a reconsideration of the paths, costs, and timetable of the hydrogen bridge to the future that was laid out in 1992.

Recognizing the globalization of energy and technology markets and that the original bridge framework is not appropriate for remote village and isolated grid environments, this reassessment also presents a second hydrogen bridge scenario, the Village Path. Finally, this paper examines liquid hydrogen as well as gaseous hydrogen, and considers fuel cell options and early niche markets in the United States with greater specificity.

Background

Concerns about the environment were initially raised in the 1960s with the popularization of Rachel Carson's book *The Silent Spring* and in 1970 with the Club of Rome study *Limits to Growth* performed by Forrester and Meadows. The later study emphasized the message that unfettered production, energy use, and resource exploitation were linked to increasing pollution levels and would lead to industrial collapse. The search began for a method of conceptualizing resource management and energy systems that will defer resource depletion as long as possible, decouple energy production from industrial output, and reduce pollution levels.

In the early 1970s the notion of a hydrogen economy was popularized by Gregory in the U.S. and DeBeni and Marchetti in Europe. Their assertion was that hydrogen could be a major energy carrier that was compatible with, and complementary to, electricity. At that time, the energy vision was of an increasingly electric future where electricity would be primarily produced by nuclear reactors until breeder reactors could be commercialized. Breeder reactors would produce more fuel than they consumed and that fuel would be used in light water reactors to produce electricity. Eventually fusion would replace all forms of fission reactors.

It was commonly anticipated that as the nuclear industry grew, both fuel and power plants would become less expensive. The cheap electricity produced from these plants could be used to produce hydrogen either through electrolysis or, in the case of high temperature gas reactors (HTGRs), as thermochemically split water. Given the prospect of inexpensive nuclear power in the mid-term, it was easy to postulate a hydrogen economy in the long-term.

Interest in a hydrogen economy waned in the late 1970s as nuclear power costs increased and disappeared in the 1980s with the termination of nuclear options in many countries, including the United States. The foreclosure of the nuclear option undermined the argument that low-cost hydrogen could be obtained from nonfossil resources in the mid-term. The nuclear-based bridge to a hydrogen economy in the mid-21st Century collapsed.

The Hydrogen Vision

Since the 1970s, environmental concerns have continued to become more acute, especially with exploding population growth and rapid industrial development throughout the world. Issues of the environment also have become globally connected issues. Issues and concerns that were once only considered in a local or national context are now perceived as international issues. Internationally common concerns about nuclear power plant accidents, atmospheric nuclear testing, acid rain, ozone depletion, and climate change all attest to the globalization of environmental issues.

In many countries, increasing concerns about carbon dioxide, ozone, nitrogen oxides, volatile organic compounds, sulfur oxides, and many other emissions have led to more stringent regulations. Under the increased severity of environmental regulations and the greater scope of environmental problems, the concept of a hydrogen energy system is very attractive. As an energy carrier, hydrogen is clean. In its purest form, hydrogen can be produced from water or biomass and is completely recyclable back to water.

At this time of increasing industrialization and population growth, the vision of sustainably produced hydrogen, driven by an inexhaustible clean energy source for the mid-21st Century, is more attractive than ever. But is there a way to bridge from our fossil fuel, nuclear, and electric present to a hydrogen electric future? Is there an affordable, acceptable, and sensible role for hydrogen that we should be developing over the next 25 to 50 years to prepare for a future hydrogen economy and, if so, what actions need to be undertaken?

Problems for Hydrogen

Over time, expanding demand and constrained supply will make traditional fossil sources less abundant and more expensive than at present. Over the past 20 years, many environmental factors have moved much of the industrial world from a nuclear and fusion future for electricity, to one based on an increasing displacement of fossil fuels by renewables into the 21st Century. While electricity produced from renewables is very clean, electricity is not a universal energy carrier. Electricity cannot, for example, be used as aircraft fuel, for long-range road vehicles, or for manufacturing processes that require a hydrogen source. Long-term electric storage is prohibitively expensive. Hydrogen could provide storage capability for electricity, fuel aircraft and ground transportation, and be used in the production of ammonia, hydrocarbons, plastics, and other products. The challenge will be finding acceptable ways of storing, transporting, and utilizing renewably produced hydrogen.

The problem for hydrogen is that the termination of the nuclear/fusion future forced what appeared to be the most direct and logical bridge to a hydrogen economy. Even with a renewable hydrogen/electric vision in place, there is no credible bridge to reach that vision. Throughout the world, practical schemes to utilize hydrogen on a wide scale will be difficult as long as fossil fuels are available and inexpensive. The transition to hydrogen would be difficult even if externalities as high as $9/MMBtu burden fossil fuels.

A bridge strategy for hydrogen will only be effective if it relies on hydrogen's unique capabilities rather than forcing hydrogen to compete with lower-cost, more convenient energy carriers that meet the same needs. In considering this statement, it should be pointed out that methane (natural gas) is also a renewable energy form; it can be produced from waste products or gasified biomass, which will not disappear as an energy carrier when the last natural gas well is depleted. Natural gas may well have a lower price than hydrogen when produced renewably. To compete with natural gas, hydrogen may have to rely on its unique chemical and physical properties.

Elements of a Bridge to Hydrogen

An evaluation of how to structure a bridge strategy will begin by examining hydrogen markets as they exist currently and in the near-term. A review of current or potential hydrogen uses between now and 2030 that have, or could have, significant markets for hydrogen are:

- Fossil fuel feedstock
- Ammonia
- Methanol
- Fuel for power generation (most attractive option is biomass)
- Space heating
- Cooking

- Fuel additive
- Aviation fuel
- Road vehicle fuel

Five of the markets are clearly not suitable as elements in a bridge strategy. Hydrogen use in bulk production of inexpensive chemicals is not compatible with hydrogen costs over $5/MMBtu. Thus, hydrogen as a fossil fuel feedstock, for ammonia production, and methanol production are not likely starting points for a hydrogen bridge. For space heating and cooking applications, hydrogen in the near- and intermediate-term offers no advantage over alternatives currently used. The situation of power generation is different. Except in unique circumstances in the near-term, fuel for power production can be provided less expensively by fossil fuels. The exception is direct production of hydrogen from biomass. At some point, when intermittent renewables such as photovoltaics are extensively used or in a village power environment, hydrogen produced by electrolysis might be an attractive and necessary form of fuel storage for transportation and power supply. The remaining four hydrogen options have potential to become elements of a hydrogen bridge strategy: biomass produced hydrogen for electric power generation, hydrogen as a fuel additive, hydrogen as an aviation fuel, and hydrogen as a fuel for road vehicles.

A hydrogen bridge strategy also must consider the status of hydrogen production, storage, and end use. A current review reveals that hydrogen is obtained primarily by processing fossil fuels (natural gas and oil) or recovered as a by-product from chemical and petroleum processing. Future production can be achieved through biomass gasification, by electrolysis with the electricity supplied by renewable sources, and eventually through various photobiological, photochemical, and thermochemical processes. Estimates for the cost of hydrogen production provided in Table 2 are based on the 1992 costs. These costs are still useful approximations of hydrogen costs today. Only the biomass production costs and target costs for photochemical and photobiological cycles appear attractive for hydrogen production.

Pipelines are not a problem for transportation and storage of hydrogen, but storage technology must be improved. For long-range transport, storage densities must approach 10% by weight for hydrogen. This is achievable with liquid hydrogen storage.

Utilization of hydrogen is a complicated issue. Three applications of interest are aircraft, ground transportation, and power generation. The major enabling technology for two of these options (ground transportation and power generation) is fuel cells. Current estimates are that early fuel cell production units will cost $2,000/kW. This is too expensive for widespread vehicle use by at least a factor of 10. The advantages of a fuel cell over a combustion turbine or other engine systems are the increased efficiency and reduced NO_x emissions. The development of a fuel cell vehicle operating on hydrogen might evolve from an engine hydrogen system in which at some future point the engine would be replaced with a fuel cell. Advances in fuel cell technology now make that strategy unlikely. It appears that in the intermediate term fuel cells will be technically competitive with hydrogen.

Potential Bridge: Centralized Hydrogen Production, Distribution, and Use

One possible bridge scenario was developed in 1992 for achieving the goal of a hydrogen electric economy. It was not assumed that it would be the only bridge or the most probable bridge. It is presented now so that others can evaluate it and identify its weaknesses or modify and improve it. That bridge scenario is presented here in three steps:

Step One (1995 - 2010) — Establish An Infrastructure

- Hydrogen gas is $6/MMBtu and biomass is $12/MMBtu until futuristic sources are available.
- A desire to evolve rather than abandon the existing infrastructures drives this bridge.
- Environmental pressures are resulting in consideration of externality costs for the use of fossil fuels realized in either higher costs or more regulation.
- The addition of small amounts of hydrogen to fossil fuels to significantly reduce emission is recognized.
- Injection of small amounts of hydrogen (5%) into the natural gas pipeline reduces nitrogen oxide emissions by up to 50% and carbon dioxide emissions at the point of use by more than 5%. Virtually all end uses would have reduced emissions and increased efficiency and would cost less than $1/MMBtu.
- If the entire pipeline system of the United States were converted to hydrogen, then almost 10 million tons of hydrogen would be consumed annually based on lower heating value.

Step Two (2000-2030) — Plugging In

- A pipeline infrastructure exists that can readily transport and store hydrogen.
- Existing extraction technology can separate and, if necessary, liquefy hydrogen on site.
- Select aviation applications are identified that will benefit from hydrogen in the intermediate term.
- The projected cost for liquid hydrogen for aircraft is $16/MMBtu for natural gas and $22/MMBtu for liquid hydrogen produced by biomass.
- As fuel cell costs are reduced, they begin to be incorporated into vehicles operating on hydrogen.

Step Three (2030-2050) — Evolving the Hydrogen Electric Economy

- Thirty years of experience with hydrogen in aviation, vehicles, and other applications has been obtained.
- Hypersonic aircraft using liquid hydrogen or slush hydrogen have been developed.

- Cost, security, and environmental problems have increased, thus lowering the use of fossil fuels.
- Affordable and efficient hydrogen storage and conversion technologies have become available.
- Infrastructure evolves from natural gas-based pipelines to hydrogen pipelines.
- Hydrogen becomes the fuel of choice for utilities when it is widely available and/or the cost of carbon-based fuels exceeds the cost of hydrogen.
- Separation of hydrogen for natural gas will be eliminated and sequestration of carbon dioxide will be less pervasive, reducing the cost and increasing the convenience of using hydrogen.

Significant changes in the aircraft and natural gas pipeline industries are assumed over the next generation for this scenario to be realized. Ultimately, extensive hydrogen use depends upon hydrogen production cost under $10/MMBtu, storage densities approaching 10% by weight, and conversion technologies with greater than 50% efficiency and costing less than $200/kW. The challenge is to structure programs carefully to provide the most sensible and affordable bridge by critically assessing the opportunities and only supporting those that have a chance of technical and economic success.

Reassessing the Centralized Bridge

Since this bridge was first proposed in 1992, four major trends have emerged that are shaping today's discussion of a hydrogen bridge.

1. There is an increasing emphasis on climate change and the specific role of CO_2 in global warming.
2. The acceptance of renewable energy, particularly photovoltaics for niche markets, has increased dramatically.
3. Restructuring of the utility industry has allowed serious consideration of distributed generation and alternate energy delivery systems.
4. The emphasis on zero-emission vehicles (ZEVs) and ultra-low-emission vehicles (ULEVs) in Southern California and a growing interest in other parts of the world has created a potential clean vehicle market for auto manufacturers.

In addition to these trends, changes in PEM (Proton Exchange Membrane) fuel cell and liquid hydrogen technologies also have warranted a reconsideration of the original bridge strategy.

<u>PEM Fuel Cell Option</u>

Improvements in the life and performance of PEM fuel cells have occurred much faster than anticipated in 1992 and these improvements could influence the structure of the hydrogen bridge. It is anticipated that by the year 2000, a PEM fuel cell will demonstrate performance equal to or better than an internal combustion engine. On the other hand, new developments in gaseous and metal hydride storage technologies have not allowed storage densities to approach 10% by weight. This has led to increasing consideration. particularly in Europe, of liquid hydrogen as the principal form of hydrogen storage for vehicles. Lack of progress in magnetic refrigeration has deferred consideration of distributed hydrogen liquefaction. The net effect of these factors indicates a need to conceive a complementary bridge that utilizes PEM fuel cells and that can be used to achieve the same hydrogen energy vision as the original bridge.

Liquid Hydrogen Option

Today, merchant hydrogen is delivered as a liquid. The exceptions are delivery by hydrogen pipelines and over-the-fence delivery of hydrogen. No hydrogen gas transfers are inter-regional today. The ease with which hydrogen liquid can be turned into a gas allows for a scenario where all hydrogen applications that can be met by hydrogen gas also can be met by liquid hydrogen. The cost of liquid hydrogen is significantly greater than hydrogen gas. However, lower storage and distribution costs and higher storage densities for many applications of liquid hydrogen could give it a more competitive cost, in units such as cost per mile, as compared to gaseous hydrogen; the converse is not true. For instance, new high-tech liquid hydrogen containers are anticipated to lower transportation costs by as much as 50%.

If hydrogen is used in aircraft, storage volume requires that hydrogen must be liquid. The International Standards Organization (ISO) is developing standards for storing and dispensing liquid hydrogen. ISO's expectation is that liquid hydrogen will be the principal means of intercountry transfer of hydrogen. Two advantages of the liquid option are that it eliminates a basic storage issue (10% hydrogen storage by weight), and it is the prime method for the delivery of merchant hydrogen today. For industrialized countries, liquid hydrogen is the default fuel for on-board storage since more than 10% of the storage system weight would be hydrogen.

A liquid hydrogen option almost certainly requires, at least through the mid-term, a centralized option for hydrogen production since economic liquefaction plants must be large. This probably means either a national electric grid with inexpensive power or steam reforming of large quantities of natural gas. Except in countries with extensive natural gas pipelines, liquid hydrogen may be the favored method of hydrogen distribution since it offers more flexibility. Until magnetic refrigeration becomes a reality, liquid hydrogen production is not an option for village power or isolated local energy systems.

Considering a Global Hydrogen Vision

Market and structural changes, coupled with an altered perception of the state of various critical hydrogen technologies, has led to the need to consider another hydrogen bridge scenario in addition to the one proposed in the original paper. To achieve a global hydrogen energy future, schemes for hydrogen energy production, distribution, and use must be developed for both electric grid-connected and non-grid-connected environments.

gaseous and metal hydride storage technologies have not allowed storage densities to approach 10% by weight. This has led to increasing consideration, particularly in Europe, of liquid hydrogen as the principal form of hydrogen storage for vehicles. Lack of progress in magnetic refrigeration has deferred consideration of distributed hydrogen liquefaction. The net effect of these factors indicates a need to conceive a complementary bridge that utilizes PEM fuel cells and that can be used to achieve the same hydrogen energy vision as the original bridge.

Liquid Hydrogen Option

Today, merchant hydrogen is delivered as a liquid. The exceptions are delivery by hydrogen pipelines and over-the-fence delivery of hydrogen. No hydrogen gas transfers are inter-regional today. The ease with which hydrogen liquid can be turned into a gas allows for a scenario where all hydrogen applications that can be met by hydrogen gas also can be met by liquid hydrogen. The cost of liquid hydrogen is significantly greater than hydrogen gas. However, lower storage and distribution costs and higher storage densities for many applications of liquid hydrogen could give it a more competitive cost, in units such as cost per mile, as compared to gaseous hydrogen; the converse is not true. For instance, new high-tech liquid hydrogen containers are anticipated to lower transportation costs by as much as 50%.

If hydrogen is used in aircraft, storage volume requires that hydrogen must be liquid. The International Standards Organization (ISO) is developing standards for storing and dispensing liquid hydrogen. ISO's expectation is that liquid hydrogen will be the principal means of intercountry transfer of hydrogen. Two advantages of the liquid option are that it eliminates a basic storage issue (10% hydrogen storage by weight), and it is the prime method for the delivery of merchant hydrogen today. For industrialized countries, liquid hydrogen is the default fuel for on-board storage since more than 10% of the storage system weight would be hydrogen.

A liquid hydrogen option almost certainly requires, at least through the mid-term, a centralized option for hydrogen production since economic liquefaction plants must be large. This probably means either a national electric grid with inexpensive power or steam reforming of large quantities of natural gas. Except in countries with extensive natural gas pipelines, liquid hydrogen may be the favored method of hydrogen distribution since it offers more flexibility. Until magnetic refrigeration becomes a reality, liquid hydrogen production is not an option for village power or isolated local energy systems.

Considering a Global Hydrogen Vision

Market and structural changes, coupled with an altered perception of the state of various critical hydrogen technologies, has led to the need to consider another hydrogen bridge scenario in addition to the one proposed in the original paper. To achieve a global hydrogen energy future, schemes for hydrogen energy production, distribution, and use must be developed for both electric grid-connected and non-grid-connected environments.

The global appeal of hydrogen is that it has the potential to free most countries from the requirement to import large quantities of oil. The global markets for vehicles, aircraft, and electricity represent growth industries through the 21st Century. Estimates are that the number of vehicles worldwide could grow by a factor of 10 over the next century. Approximately 40% of the human race has no access to electricity and many of those who have access are served by electricity that is either unreliable or not available 24 hours per day. Such unfulfilled demand makes it an imperative to develop cleaner methods of transportation and power production that will be globally applicable and that can reduce environmental degradation.

Given the structural changes in electric utility markets, with their eventual globalization, and the existence of global vehicle and aircraft markets, the focus of a global hydrogen vision coincides with a shift to marketing products that could operate globally on hydrogen. Satisfying the demand for clean electricity, cars and aircraft with hydrogen-fueled products will, in turn, drive the development of adequate hydrogen production and storage to support it. It has been recognized for more than a decade that automakers must make world cars and aerospace companies must design and sell aircraft globally. With the restructuring of the electric utility industry, utilities are forming subsidiaries that are looking beyond their home territories and countries, as well as signing worldwide agreements to provide energy to industrial and commercial clients. The major markets identified in the original paper are, or are in transition to, becoming global markets.

Another Bridge — The Village Path

The original bridge strategy only addressed the grid-connected environment. In many regions of the world, from Alaska to the tropics, potential electricity users cannot connect to a national electric grid. There are many environmental, political, and economic reasons for wanting to provide electricity to remote villages and isolated grids and to consider hydrogen as the fuel for the electricity.

In Alaska, for example, much electric generation is provided using petroleum to operate diesel generators and to provide home heating and fuel transportation. Fuel costs are very high, with electricity costs in some villages approaching $1/kWh. Pollution from oil spills is also a major and continuing problem. In this harsh environment, fuel can only be provided during part of the year and fuel supplies must last through late fall, winter, and into spring. Renewable energy could be used to produce electricity and hydrogen year-round. Such an energy system could be more reliable and, once installed, not as expensive as the current energy system. This situation represents a potential early market in which to demonstrate sustainable energy systems.

For energy systems that are isolated or are part of a local grid with local hydrogen production and use, a gaseous hydrogen production and distribution option is most likely. Electricity can be generated from renewable sources other than biomass, but many renewable sources are intermittent and require storage which hydrogen can provide. In a village environment, without access to indigenous sources of fossil fuel, a renewably-based electric system would be necessary to support the production of hydrogen. An alternative strategy is to seasonally deliver hydrogen as petroleum is now delivered and have the capacity to store hydrogen for 6 to 9 months. In other environments storage requirements might not be so severe, but for remote sites or severe climatic conditions, significant storage may be required. The development of the scenario for locally produced hydrogen would require gas storage, at least in the intermediate term. The steps for such a system would include:

Step One (1995 - 2010) — Renewable Electric Generation

- Assess the renewable resources available and install the appropriate solar, wind, geothermal, biomass, hydroelectric, or other renewable system to generate electricity.
- Generate hydrogen through electrolysis using excess renewably generated electricity from intermittent sources.
- Demonstrate hydrogen production from biomass gasification and generate power with a combustion turbine.
- Use the hydrogen produced to operate vehicles; these may include autos, buses, motor boats, or ski mobiles.
- Demonstrate electricity production from a stationary fuel cell operating on hydrogen.

Step Two (2000 - 2030) — System Integration

- Demonstrate a complete village energy system that produces electricity directly and uses renewably produced hydrogen that is stored as a gas for supplemental electric production.
- Using stored hydrogen, produce electricity with combustion turbines and fuel cells, operate vehicles, and provide heating (space, water, and food).
- Develop and demonstrate a similar total energy system using biomass, perhaps with CO_2 separated from the hydrogen.

Step Three (2020 - 2050) — Demonstration of Sustained Hydrogen Electric Systems

- With more than 20 years of experience in developing and maturing total energy systems, standardize components and designs that allow all components to be "plug and play."
- Design and demonstrate systems which allow for renewable forms of electric generation and various kinds of hydrogen production to be integrated with small-scale liquefaction technologies for more efficient storage and also to provide aircraft fuel.

The economics for renewable technologies must be comparable in cost for performing the same function as the energy source that is being replaced. If photovoltaics are replacing storage batteries costing $35/kWh in the Andes so that villagers can watch a World Cup Soccer match on television, then photovoltaics or wind systems are economical. If a remote village has no power, then the price paid for renewables can be economical, even if it is a significant portion of a family's available income, as is the case in remote Alaska. In the long term, advances in PV, wind, solar thermal, and biomass technologies and manufacturing techniques will allow the penetration of these technologies into virtually all energy markets. The largest factor in decreasing prices are increases in production capacities. The deployment of these technologies in remote locations supports the development of a bridge for a hydrogen vision.

This "village path" strategy must be examined to assess whether it is practical and the details must be developed; however, any alternative to a renewable path is likely to add to environmental problems around the world as fossil fuel use increases with growing populations and intensified industrialization.. As nations are forced to greatly increase purchases and use of fossil fuel, especially petroleum, energy will continue to drain their economies.

Conclusion

This paper presents two different bridges to achieve the same energy vision: centralized production, distribution, and use of hydrogen; and dispersed production and use of hydrogen. In industrialized countries, the centralized approach favors the use of hydrogen gas in gas pipelines with centralized use at power plants and liquefaction at airports. Distributed use from centralized hydrogen production favors centralized liquefaction and distribution of the liquid to decentralized locations such as distributed generators, small airfields, and gas stations without the requirement of a hydrogen gas distribution system. Local production of hydrogen and village power favors the use of hydrogen gas for all non-aircraft needs. Aircraft hydrogen fuel needs would be met locally when some form of magnetic refrigeration is developed. Over the next decade, additional patterns of hydrogen development will emerge.

It is clear that renewables are the key to sustained hydrogen development. The incremental addition of hydrogen production and storage to installed renewable technologies is likely to emerge as the path to energy independence for village power and a bridge to a hydrogen electric future. Fuel cells are the linchpin that connects renewable systems to meet electric production, space conditioning, and ground transportation needs. The use of local resources will be required to reduce pollution, foster economic stability, and provide long-term access to an improved quality of life. Over the next decade, efforts should be made to demonstrate sustainable hydrogen systems in realistic environments, test their viability, and gain experience with their performance.

TABLE I
Possible Hydrogen Applications in the Intermediate (1990-2030) Time Frame

Possible Application	Alternative Today	Potential Market Size (1) (1990-2030)	Value of Hydrogen 1990-2030 (1990 $/MMBTU)	Future Value (~2050) (1990 $/MMBtu)
Industry				
Fossil Fuel Processing	Captive H_2	Large	5	N/A
Ammonia	None	Large	5	?
Methanol	Captive H_2	Medium	5	N/A
Glass	None	Small	>25	>25
Food	None	Small	>25	>25
Metals	Forming Glass	Small	10-25	10-25
Polysilicon	None	Small	>25	>25
Drugs	None	Small	>25	>25
Electric Utility				
Fuel (Power Plant)	All energy sources	Large	5-18 (2)	15 (3)
Biomass - derived H_2	All energy sources	Medium	5-18 (2)	15 (3)
Fuel Additive	None	Medium	10-25	N/A
Corrosion Control	None	Small	>25	>25
Generator Cooling	None	Small	>25	>25
Transportation				
Aviation	JP-X	Large	10-25 (liquid)	10-25 (liquid)
Road Vehicles	Gasoline, CNG, batteries	Large	9-18 (2)	15-30 (4)
Fuel Additive	None	Medium	5-25	N/A
Aerospace	None	Small	15-25 (liquid)	15-25 (liquid)
Buildings				
Heating	NG, electricity	Large	3-6	10 (5)
Cooking	NG, electricity	Large	3-6	30 (6)
Fuel Additive	None	Medium	5-25	N/A

Notes:
(1) Large is greater than 1 million tons per year; small is less than ten thousand tons per year.
(2) $18/MMBTU assumes $9/MMBTU added for "environmental externalities."
(3) Capped by electricity from renewable sources.
(4) Capped by $.10/kWh electricity.
(5) Capped by heat pump with $.10/kWh electricity.
(6) Capped by $.10/kWh electricity.

Table II: Hydrogen Production Costs

Today	Future	Date Available	Cost ($/MMBtu)
Reforming Natural Gas		Now	5
Water Electrolysis		Now	25
Partial Oxidation of Oil		Now	9
Coal Gasification		Now	10
Biomass Gasification		Now	12
	Wind/Electrolysis	1995-2000	30
	Photovoltaic/Electrolysis	2000	30-50
	Thermochemical	>2030	30
	Biochemical/Photochemical	>2030	Goal of 10
	Photoelectrochemical	>2030	Goal of 10

Table III: Hydrogen Storage

Technology	Percent By Weight Hydrogen	Comment
Pressurized Gas @200 Atm*	1-5	Low Density
Liquid in Aluminum Vessel	10-25	Expensive, Inefficient
Metal Hydride ($FeTiH_2$)	1.4-4.0**	Low Density, Inefficient
Activated Carbon	4-8	Inefficient, Cost Unknown

* Higher pressure tanks may be able to achieve hydrogen density greater than 10% by weight.
**Higher temperature metal hydride can store hydrogen at 6% by weight.

Table IV: Renewable Electric Technologies

Technology	Date Available	Estimated Cost (Installed)
Photovoltaics	Now	$3 to $7/watt
Wind	Now	$910/kW
Biomass/Solar Stirling Engine	2000	$2000 to $3000/kW

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Support by U.S. Department of Energy and Disclaimer

The development of this paper by the National Hydrogen Association is supported by a cooperative agreement with the U.S. Department of Energy (DOE), DE-FC36-95GO10125. This support, however, does not constitute an endorsement by DOE of the views expressed in the article.

Acknowledgements

The authors would like to acknowledge the suggestions of NHA Board members for their input into this paper:

Bud Beebe, Sacramento Municipal Utility District
Dominique Kluyskens, Hydro-Québec
Frank Lynch, Hydrogen Consultants, Inc.
David Nahmias, David Nahmias and Associates, Inc.
Keith Prater, Ballard Power Systems
Sandy Thomas, Directed Technologies, Inc.

The following staff are acknowledged for their assistance in editing this paper:

Jacquie Cochran, National Hydrogen Association
Paula Eidson, National Hydrogen Association
Wendy Rodenheiser, Technology Transition Corporation

This paper represents an updated version of the paper presented at the Ninth World Hydrogen Energy Conference, "A Bridge to the Future: Hydrogen-Electric Economy," co-authored by the Electric Power Research Institute and the National Hydrogen Association. The NHA would also like to acknowledge the contributing authors of that paper:

James K. Birk, Electric Power Research Institute
Bhupen (Ben) Mehta, Electric Power Research Institute
Arnold Fickett, Energy Consultant

Appendix D

7th Annual U.S. Hydrogen Meeting Proceedings

Removed for separate processing —

Appendix E

Strategic Planning for the Hydrogen Economy: The Hydrogen Commercialization Plan

Review Draft

Strategic Planning for the Hydrogen Economy:
The Hydrogen Commercialization Plan

November 1996

National Hydrogen Association
1800 M Street, N.W., Suite 300
Washington, DC 20036-5802

Strategic Planning for the Hydrogen Economy: The Hydrogen Commercialization Plan

A sustainable hydrogen energy industry — an energy system based upon the extensive use of hydrogen as an energy storage and transportation medium — must be established if an environmentally and economically sustainable world is to be left to our children and grandchildren. Few doubt that the hydrogen energy industry will eventually evolve. Many debate the timing of such a development. Only by defining the nature of a future hydrogen energy system, by identifying the path to such a system, and by actively taking the first steps along that path will we, as a world society, achieve that goal in time to avoid serious environmental and economic disruptions.

The National Hydrogen Association, in conjunction with the U.S. Department of Energy, is embarking upon the process of defining the path and beginning the journey. The NHA believes that this journey will only be successful by working together in an industry/ government partnership. Neither group can succeed alone. Both have unique strengths and weaknesses.

Industry has the expertise and financial resources to bring new products to the marketplace. But industry must respect the bottom line and the demands of its stockholders to provide short-term return on investment. Industry cannot finance long-term societal goals such as clean air and reduced dependence on foreign oil.

Conversely, governments are notoriously sluggish and inefficient whenever they attempt to force new technology on the marketplace; witness the synthetic fuels fiasco. But governments have the sole charter to "protect the commons" — in this case, the environment — from the excesses of individuals or corporations pursuing their own economic self-interest. Government alone has the long-term staying power and the mission, acting on behalf of all citizens collectively, to develop and promote new technology and new policies that will achieve societal objectives. Working together, government can provide the seed money and regulatory environment to start the process, and industry can provide the marketplace savvy and the large capital investment, once the hydrogen technology development comes within industrial planning horizon time scales.

Objectives of the Hydrogen Commercialization Plan

This hydrogen commercialization plan is one major tool needed to implement the National Hydrogen Association mission statement:

> ...to foster the development of technologies and their utilization in industrial and commercial applications and promote the transition role of hydrogen in the energy field.

The Hydrogen Commercialization Plan is a living document to be revised and expanded over the coming years as more and better information becomes available about new technologies and the growing market for hydrogen energy systems.

The primary objective of the plan is to obtain commitments from both industry and government to begin implementing the hydrogen energy industry. Such joint commitment will require an economically and technically feasible roadmap on how to get from here to there. Industry must be convinced that it can eventually make a return on investments in hydrogen technology. Government must be convinced that its investments will leverage larger societal benefits in the form of reduced health costs, reduced oil imports, and improved international competitiveness over time. In short, the hydrogen commercialization plan must point to a credible benefit/cost ratio for all participants.

It is our intention that this plan will be used to:

- identify unique niche market opportunities where hydrogen is economical now, or nearly so, with growth potential toward longer-term goals.

- convince appropriate companies, both members and nonmembers of the NHA, to make investments in hydrogen development, demonstration, and commercialization projects, with industry paying an increasing share of the cost as each technology approaches market viability.

- convince government decision makers to provide steadily increasing support for hydrogen and fuel cell development programs in the near-term, with the realization that these technologies will eventually become economically viable on a broad scale without any government support.

- help guide hydrogen energy investment choices by government agencies in the industrialized world, including choices by the U.S. Department of Energy.

- help convince other key players — such as state and local officials, building inspectors, the insurance industry, the investment industry, and the public at large — that the hydrogen energy industry is safe, economical, and sustainable.

- encourage other companies and organizations to join the NHA.

This commercialization plan begins by identifying the most likely early markets for hydrogen as an energy carrier, and sets realistic near-term and mid-term goals for selected market penetration. The plan outlines the incentives (see Appendix I) and the major barriers to achieving those goals, and recommends activities to capitalize on the incentives and overcome the market barriers.

Opportunities for early market entry exist near hydrogen plants and by-product hydrogen sources. Infrastructure growth potential is most favorable where natural gas or off-peak electricity prices are low. The locations of existing renewable energy facilities point the way toward the future. This information is presented in the maps in Appendix II.

Appendix III contains brief summaries of a few specific markets for hydrogen energy. NHA members and other hydrogen advocates are encouraged to contribute additional summaries and to approach these markets as teams with the ability to exploit them.

The plan identifies specific action items to overcome each major barrier, with primary emphasis on near- and mid-term results, with the understanding that the transition from fossil-based fuels to sustainable, renewable hydrogen is the most difficult task. Taken together, these actions will provide a realistic transition path toward the Hydrogen energy industry.

The Market Sectors

In a truly sustainable world, all energy will be carried by either hydrogen or electricity; carbon-based fuels will not be acceptable. Hydrogen will become especially important in those economic sectors in which storage or transportation of energy is required and electricity is less effective or more costly as an energy carrier.

Transportation

A municipal subway system may be powered economically with electricity from a fixed source delivered to the trains by wires or rails. But a personal automobile intended for a trip from Seattle, Washington, to Los Angeles, California, requires that a fuel be stored onboard the vehicle. Hydrogen will be that fuel in a sustainable world.

Other terrestrial transportation requirements will also be logical markets for hydrogen-fueled vehicles. These markets include trucks, buses, and, in some locations, trains. All water and air transportation activities will be fueled by hydrogen, since electricity from fixed sites is impractical and no foreseeable battery technology will suffice.

Fixed Power Plants

Hydrogen will also play a role in the generation of electricity at fixed power plants. In addition to the present use of hydrogen as a coolant for electrical turbines, hydrogen will become a fuel. In those remote locations without an electrical grid, electricity from solar, wind, tidal, and other renewable sources will be used increasingly in a sustainable world. These sources of electricity are often intermittent and require a storage component. Even relatively steady sources of electricity, such as hydropower, may benefit economically from an energy storage system to meet peak power requirements. Hydrogen produced from off-peak or surplus power can be used to store energy for delivery — as electricity — when needed.

Ultimately, hydrogen will be available to each residence and business through a pipeline infrastructure, analogous to the present natural gas pipeline network. Hydrogen will be used to supply electricity to each home and business by locally sited fuel cells which provide the electricity as well as space heating, with no air or water pollution, in a quiet unobtrusive manner compatible with our daily environment. Such a distributed generation system may eliminate the need for large, central power plants and provide electric utilities with increased flexibility in the design of their systems. Indeed, natural gas-powered stationary fuel cells are already sold as environmentally clean distributed cogeneration power systems, serving as a test bed and precursor to future hydrogen-powered cogeneration systems.

Industrial Applications

While the transportation and fixed-site electricity markets are the most challenging and the highest profile areas for the growth of a hydrogen energy industry, many present and new industrial applications for hydrogen also will develop. Most industrial applications can be effectively served by electricity. Exceptions are those industries that produce low-cost hydrogen as by-products or those that already use hydrogen for other purposes. These industries may provide the initial sites for acceptance of transportation and fixed-site electricity generation using hydrogen.

While industrial applications must and will be pursued, it is important that these not distract from efforts to achieve the broader public use of hydrogen in transportation and fixed-site electricity generation, which is the primary focus of this NHA commercialization plan.

Hydrogen Commercialization Goals

For planning purposes, the National Hydrogen Association has set market penetration goals in the two primary market sectors identified above. These goals should be considered preliminary, and will be modified in response to new information, including new technological developments and further hydrogen systems analyses. While these goals may change, it is important to establish commonly shared benchmarks now, so that all participants can focus and coordinate their efforts.

Achieving these goals will require significant contributions and continued successful technological developments in areas outside the scope of the U.S. Department of Energy's Hydrogen Energy Program, which is part of the Office of Utility Technology under the Assistant Secretary for Energy Efficiency and Renewable Energy. Meeting the transportation goals listed below will require the successful development of either hybrid electric vehicles with hydrogen-fueled internal combustion engines or direct hydrogen fuel cell vehicles.[1] In the United States, both the hybrid and the fuel cell for transportation programs are managed by the Office of Transportation Technology, separate from the Hydrogen Energy Program.[2]

A viable hydrogen-fueled vehicle also will require improvements in other electric vehicle components such as electric motors, controllers, and peak power augmentation devices. And, most importantly, the transportation goals will only succeed if public acceptance and demand for value-added products allows the automobile industry to put hydrogen-fueled vehicles into mass production. Hence, the goals listed below are joint industry/government goals. The NHA action items listed in subsequent sections of this plan, however, will address primarily those areas where NHA and its members can make the greatest impact, such as in hydrogen fuel supply. We assume that other players will buy into these broader goals and jointly pursue these common goals.

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[1]Nonhybrid internal combustion engine vehicles operating on either neat hydrogen or mixtures of hydrogen and natural gas will play a role in early niche markets, since they offer the promise of lower emissions to help meet local air pollution goals. But without the boost in efficiency and significantly reduced emissions offered by hybrid or fuel cell vehicles, it would be very difficult to compete with other alternative fueled vehicles in the long run.

[2]Although we refer frequently to the U.S. Department of Energy Hydrogen Program, the National Hydrogen Association includes many industrial members outside the United States; the hydrogen energy industry will be an international development. Many of the DOE references apply to other government energy agencies throughout the industrialized world.

Similarly the fixed power plant goals assume continued development of stationary fuel cells, hydrogen storage, and fuel cell/grid interface hardware. And our common goal of renewable hydrogen energy depends strongly on reduced costs for photovoltaics, wind energy, solar thermal generators, and biomass energy farms. We assume here, however, that the limited funding available to the Hydrogen Energy Program could have very little impact on reducing the costs of PV, for example. Diverting even a portion of a $14 million annual hydrogen program to assist a $90 million PV program or a $300 million solar energy program would not be appropriate. This plan, therefore, assumes that PV and other solar options will develop on their own time-scale, and the hydrogen program should concentrate strictly on hydrogen-related components of remote power systems, including electrolyzers, stationary hydrogen storage, and fuel cell systems. Renewable hydrogen energy will enter the marketplace when and where it is cost-effective compared to the other local forms of energy.

With these caveats, the National Hydrogen Association recommends the following goals for the joint industry/government hydrogen energy program.

Transportation Goals

Hydrogen Vehicle Demonstration Goal

By 2000, establish at least three new hydrogen vehicle demonstration projects, including local hydrogen production by small-scale steam methane reforming or small-scale electrolysis, and dispensing to service at least 10 hydrogen-powered vehicles each. Vehicles may store gaseous or liquid hydrogen, and the fuel might include mixtures of hydrogen and natural gas. At least one demonstration project will produce hydrogen from a renewable resource (solar, wind, or biomass) or from municipal solid waste.

Hydrogen Bus Goals

1. By 2005, operate at least 100 hydrogen-powered buses on regularly scheduled routes. Cost goals include hydrogen-fueled ICE hybrid or fuel cell power train systems at less than $500/kW and dispensed hydrogen costing less than $4/kg ($9.45/1,000 SCF) for bus refueling.

2. By 2010, 50 percent of all new buses shall be powered by hydrogen. Cost goals shall include hydrogen-fueled ICE hybrid power train or fuel cell production costs less than $80/kW[3] and delivered hydrogen costs of less than $3/kg ($7.09/1000 SCF), made from natural gas at $4/MBTU ($4.05/1000 SCF) or from renewable resources, including municipal solid waste.

Hydrogen-Fueled Passenger Vehicle Goals

1. By 2010, produce enough hydrogen to supply 50 percent of all new vehicles sold under the California Zero-Emission Vehicle (ZEV) program (including other opt-in states), on the assumption that half of these vehicles will be hydrogen-fueled.[4]

2. By 2015, produce enough hydrogen to supply 25 percent of *all* new passenger vehicles. Cost goals include hydrogen-fueled ICE hybrid power train or vehicle fuel cell systems at less than $35/kW and delivered hydrogen at less than $2.50/kg ($5.91/1000 SCF) from natural gas at $4/GJ ($4.05/1000 SCF).

Fixed Power Plant Goals

Grid-Connected Goals

1. By 2002, install at least 50 MW (cumulative) of hydrogen-powered[5] fuel cell electricity for distributed, grid-connected power in the world.

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[3]All price goals are in constant 1996 U.S. dollars.

[4]The primary alternative for the ZEV market is assumed to be the battery-powered electric vehicle, so this goal assumes that hydrogen-fueled vehicles are competing only against battery vehicles, giving the hydrogen-fueled vehicle great competitive advantage in terms of weight and range. Assuming that the California ZEV requirements resume in 2003, the total ZEV market could reach 15 percent of all new vehicles by 2010, including the original five opt-in states. This hydrogen goal, therefore, could reach 7.5 percent of all new vehicle sales. For comparison, the current DOE Hydrogen Program goal states that 25 percent of *all* new vehicles be hydrogen-powered by 2010, which implies sales on the order of two million hydrogen-powered vehicle annually.

2. By 2015, 10 percent of all new electrical generation capacity shall be from hydrogen-powered fuel cell [cogeneration] systems. [Alternative: By 2005, hydrogen-powered fuel cells will supply 50 percent of new market 'High Quality Power' applications, replacing the need for onsite "emergency" generators and UPS systems.]

Remote Power Goals

1. By 2005, establish at least two remote village power demonstration projects using intermittent renewable energy sources and hydrogen to store energy. Cost goal for the energy derived from hydrogen storage shall be less than the cost of battery storage for storage periods longer than four days.

2. By 2015, install at least 5 MW of remote renewable power systems with hydrogen storage. Cost goal for hydrogen energy shall be less than the cost of battery storage for storage periods longer than two days. [Should remote power systems have higher MW goal than grid-connected, since remote power can afford higher initial costs and may be a faster growing market in the developing world?]

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[5]The hydrogen for stationary fuel cells will undoubtedly be derived onsite from natural gas initially, leading some to question whether such "natural gas systems" are appropriate for NHA and DOE hydrogen energy program support. However, these fuel cell systems will help to develop low-cost, small-scale, steam-methane reformers that may be essential to providing inexpensive hydrogen for fuel cell vehicles. Stationary fuel cell developments also may advance the technology for transportation fuel cells. Both are worthy hydrogen energy objectives.

Market Incentives and Barriers

To accomplish these goals, we must capitalize on the incentives for hydrogen energy use and overcome the barriers to its use.

Hydrogen Incentives

Hydrogen has three main advantages relative to existing hydrocarbon fuels:

- No local air pollution [volatile organic compounds (VOC), carbon monoxide (CO), oxides of nitrogen (NO_x), and particulates under 10 microns (PM-10)];
- Reduced oil consumption; and
- No greenhouse gas emissions (during use).

Electricity also has these same three attributes, so the main incentive for using hydrogen over electricity occurs under two circumstances: when storage is important, such as in transportation or remote village applications, or when hydrogen can be made at lower cost than electricity, such as from biomass or municipal solid waste gasification. The key to any successful hydrogen plan, therefore, is to exploit these advantages of hydrogen, particularly in those market segments that require energy storage or energy for transportation.

Hydrogen Barriers

Analyzing the barriers to hydrogen market entry can provide valuable insight into the most effective use of the NHA, industry, DOE, and other international resources to help jump-start the hydrogen energy industry. By honestly identifying and analyzing the major roadblocks as seen by others, we can work to overcome the barriers.

Market barriers may be different for various participants in the journey toward the hydrogen energy industry. For example, car owners, vehicle manufacturers, hydrogen gas producers, and government officials may have different perspectives and see market penetration differently. Consumers might regard safety as the most important barrier, for example, while gas producers have learned to handle hydrogen safely and may consider the lack of hydrogen vehicles as the major barrier to increased use of hydrogen as an energy vector. Table 1 includes our judgment of how four major segments of society critical to the implementation of the hydrogen energy industry might perceive hydrogen market barriers.

Table 1. Potential Hydrogen Barriers for the Transportation Market

Car Owner Barriers	Safety/Confidence
	Lack of Pervasive Hydrogen Fueling Options
	Cost
Vehicle Industry Barriers	Cost
	Lack of Fueling Infrastructure
	Onboard Hydrogen Storage
	Return on Investment (compared to conventional vehicle investments)
	Large Investment Required
	Lack of Hydrogen Codes and Standards
	Safety
Hydrogen Gas Industry Barriers	Lack of Hydrogen Vehicles
	Difficulty Obtaining Insurance
	Return on Investment (compared to other gas industry investments)
	Large Investment
	Geographically Dispersed Investments
	Long Payoff Time (dependent on vehicle penetration)
	Local Fire Marshall (regulations, codes, and standards for fueling stations)
	Safety
Government Barriers	Minimal Political Awareness, let alone Support
	Budget Constraints
	Lack of Consensus to Reduce Greenhouse Gases and Move toward a Sustainable Energy Economy

For the transportation sector, considering all four interest groups summarized in Table 1, the most challenging barrier at this time may be the lack of a hydrogen infrastructure. U.S. automobile companies, thanks to the cost-shared DOE fuel cell vehicle programs, are gaining confidence in the technology of PEM fuel cell powered passenger vehicles. However, they are deterred by the lack of a hydrogen-fueling infrastructure. General Motors and Daimler-Benz have announced their intention to use methanol in their early fuel cell vehicle designs.[6] The Chrysler and Ford fuel cell vehicle cost-shared contracts with DOE originally specified gaseous hydrogen onboard storage, but now Chrysler is considering gasoline with an onboard fuel processor to avoid any new fuel infrastructure development, leaving Ford as the only major automobile manufacturer actively evaluating the direct hydrogen approach in the United States. In addition to Daimler-Benz, BMW has a long history developing liquid hydrogen onboard storage for use in conventional ICE vehicles, and they have recently announced plans for a passenger-size fuel cell vehicle using liquid hydrogen. Toyota has introduced a fuel cell vehicle and Mazda is working on a hydrogen rotary engine.

The near-term choice of onboard fuel (hydrogen versus liquid hydrocarbons such as gasoline or alcohols) will be determined by the technical feasibility, the global climate change implications, and the cost of mass-producing onboard partial-oxidation fuel processing systems or onboard methanol steam reformers, compared to the cost of providing a geographically distributed hydrogen-fueling infrastructure. But even if gasoline or methanol become the initial fuel of choice for hybrid electric or fuel cell vehicles, society will eventually have to make the transition to hydrogen, since the world must eventually develop sustainable energy systems which don't use carbon-based fuels.[7]

The primary challenge for the NHA and its members, then, is to develop a cost-effective, geographically dispersed, hydrogen-fueling infrastructure. This infrastructure will undoubtedly be based on fossil fuels initially, but the hydrogen must eventually be supplied by renewable resources as they become cost-competitive in the decades ahead. Developing a credible plan for such an infrastructure would provide the automobile industry the confidence it needs to move more quickly to hydrogen-fueled passenger vehicles.

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[6]Daimler-Benz had to use compressed hydrogen in its first two prototype fuel cell vans, since development of an onboard chemical processor to produce hydrogen from methanol is a major technological challenge. Packaging compressed hydrogen tanks into a passenger van proved significantly less challenging than installing an onboard chemical factory.

[7]Methanol, although derived exclusively from nonrenewable natural gas at this time, could be produced by gasification of biomass or municipal solid waste. Hydrogen can also be produced from biomass and MSW with higher efficiency and lower cost. And, unlike hydrogen, methanol cannot be made directly from solar energy, wind, or hydroelectric power. Therefore, a methanol-based energy system would significantly limit our options as the world moves toward energy sustainability.

To summarize, the key barriers to market penetration in the transportation sector may be:

- The hydrogen infrastructure/hydrogen vehicle "chicken and egg" problem (gas producers will be reluctant to install hydrogen-dispensing stations until hydrogen vehicles are on the road, and the automobile industry will be hesitant to build vehicles until there are many refueling stations);
- Safety or perceptions of hydrogen risk;
- Perceived difficulty of onboard hydrogen storage;
- High initial cost;
- Large investment requirements;
- Uncertain return on investment;
- Difficulty obtaining insurance; and
- Lack of codes and standards or accepted common practices.

The market barriers for grid-connected stationary power production appear to be less than for those for transportation applications. For example, the first three transportation barriers listed above will be reduced or eliminated for a stationary hydrogen power plant. Safety concerns will be lessened since the power plant will be at a fixed site and initially will be installed and operated either by a utility or by a commercial customer with skilled maintenance workers. This is a much lesser risk compared to installing and operating a hydrogen storage system onboard a private automobile.

There will be no "chicken and egg" dilemma with respect to hardware production since each stationary system is produced and sold by a single company.[8] There is no need for cooperation between two different industries to make joint investments in manufacturing equipment, although marketing these systems in some locations brings the natural gas industry into conflict with the electric utility industry. And there is nothing equivalent to the onboard storage barrier in the stationary market; natural gas is consumed as needed to produce hydrogen.

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[8]Assume that the electric and gas utilities are handled by the same company. If not, then cooperation is still required between the electric utility and the gas utility, but this cooperation is trivial compared to the coordination required between hydrogen suppliers and automobile manufacturers.

Furthermore, the cost barrier for fuel cell systems may be less difficult — by as much as a factor of 10 — for stationary utility systems than for mobile fuel cell systems (e.g., \$500/kW versus \$50/kW). This is the case even though stationary fuel cells must operate uninterrupted around-the-clock for at least five, if not ten, years (45,000- to 90,000-hour life), compared to an automotive fuel cell that might only need to operate one or two hours per day for ten years (3,000- to 5,000-hour life). Also, the automotive fuel cell is rated by peak power that is rarely used, while the stationary fuel cell normally operates near its rated capacity most of the time.

Thus, a vehicle fuel cell costing \$50 per peak kilowatt might have an effective cost of \$350 per average kilowatt produced. On the other hand, stationary fuel cells operate in a much more controlled environment than mobile fuel cells, with steady-state operation and little shock and vibration, reducing cost drivers. In short, the stationary fuel cell system is significantly different from the mobile fuel cell system.

But introducing stationary fuel cells may not contribute significantly to societal objectives of reduced oil imports, reduced urban air pollution, and reduced greenhouse gas emissions. Displacing coal, natural gas turbine, or nuclear-powered electricity with natural gas-powered fuel cell electricity will do nothing to cut oil imports. Stationary fuel cell systems will only reduce urban air pollution in those areas where they displace electrical generators that are located within the urban airshed. Otherwise, the existing fossil fuel plant VOC and NO_x emissions from plants outside the urban areas do not contribute to photochemical ozone formation in the local atmosphere. Stationary natural gas-powered fuel cells will reduce greenhouse emissions by displacing fossil fuel-based electricity, but natural gas-powered gas turbines provide almost the same advantage.[9] We conclude that the transportation market, although more difficult to penetrate, should remain the primary initial target of the hydrogen commercialization plan.

[9]In fact, greenhouse gas emissions could increase if stationary fuel cells displaced advanced gas turbines, since the combined efficiency of the natural gas reformer needed to produce hydrogen (70 percent) and fuel cell (55 percent) could be lower (e.g., 38 percent) than the efficiency of a natural gas turbine (e.g., 43 percent).

Remote power applications may have some unique barriers. Since the primary market may be outside the industrialized countries, financing may be a roadblock in many developing countries. Maintenance of the relatively complex electrolyzer/hydrogen storage/ fuel cell/inverter system may be difficult in remote locations compared to the alternative: storage batteries. Many manufacturers of remote renewable power systems may be unaware of or uncomfortable with a hydrogen storage system technology compared to the conventional battery energy storage, or they may be unaware of the economic advantages of energy storage for their customers.

On balance, however, the barriers to the stationary fuel cell market appear to be less daunting than the challenges faced by the hydrogen transportation market. But the societal rewards for penetrating the transportation market are also substantially greater. Penetration of the utility market with stationary fuel cells will benefit only one of the three major societal goals: replacing coal-generated electricity with natural gas/hydrogen/fuel cell-generated electricity will reduce greenhouse gas emissions.

The Plan's Approach to Overcoming Market Barriers

A successful hydrogen development program must address and eventually overcome each of these barriers, while exploiting the incentives to use hydrogen. The NHA hydrogen commercialization plan seeks to address each of the market entry barriers, as discussed in the following sections. We begin with the transportation market, since the barriers appear to be higher.

Overcoming Transportation Market Barriers

Overcoming the Chicken and Egg Dilemma. The plan emphasizes four elements that will assist both hydrogen gas suppliers and hydrogen vehicle manufacturers to overcome their reluctance to enter the market. We can ease the chicken-and-egg dilemma with a combination of:

- using existing excess by-product hydrogen or excess merchant hydrogen capacity, either liquid or gaseous[10];

- developing small-scale hydrogen generators, using either electrolysis or fossile fuel processors[11];

- starting hydrogen vehicle sales with centrally refueled fleet applications, including buses and both government and private passenger vehicle fleets; and

- establishing hydrogen corridors to connect islands of hydrogen fueling stations constructed earlier for the hydrogen-fueled vehicle fleets.

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[10] Hydrogen used in the chemical industry may not be directly suitable for transportation applications. In particular, the hydrogen stream may contain impurities and water vapor that would have to be removed at added expense before being compressed and stored for transportation purposes.

[11] The primary stationary fuel processor is expected to utilize steam-methane reforming. However, other stationary hydrogen generators might use partial oxidation (no catalysts or steam) or autothermal reforming (downstream catalysts plus steam) of heavier hydrocarbons including methanol, ethanol, gasoline, naptha, or heavy oils. In addition, the DOE's Office of Transportation Technology is actively supporting onboard liquid hydrocarbon processors to provide the hydrogen for fuel cell vehicles. The NHA commercialization plan does not endorse these onboard fuel processing programs since they would not directly promote our end goal of a sustainable hydrogen energy industry, nor do they maximize societal objectives of reduced air pollution, greenhouse gas emissions, or reduced oil imports.

In the very early days of hydrogen vehicle market penetration, there will be too little demand to justify building new conventional hydrogen production capacity. Gas suppliers generally build very large steam methane reformers to reduce the cost of hydrogen. For example, a typical 30 metric tonne per day plant would provide enough hydrogen for a fleet of about 40,000 hybrid-ICE or 60,000 fuel cell passenger vehicles. It may take many years before there are 40,000 to 60,000 hydrogen-fueled vehicles within range of a given gaseous hydrogen plant.

One solution is to find centrally fueled vehicle fleets that are located near existing hydrogen plants or chemical plants with excess hydrogen capacity. The hydrogen gas merchants might install refueling stations on their property to sell excess hydrogen and improve their capital recovery and profitability. In some cases, industrial hydrogen gas users that are already served by hydrogen pipelines might be induced to fuel their company vehicles with this readily available on-site hydrogen.

Another option would be to utilize liquid hydrogen, installing liquid hydrogen storage tanks and vaporizers at the fleet operator's refueling facility. Liquefaction of hydrogen adds more to the cost, but opens up larger geographic areas. This is because liquid hydrogen can be transported economically by cryogenic tanker truck up to a thousand miles away, while gaseous hydrogen pipelines are generally limited to a few tens of miles and, even then, only for very large consumers.

The hydrogen infrastructure problem also could be alleviated by developing small-scale hydrogen generators, either small-scale electrolyzers or small-scale fuel processors, such as steam methane reformers. These hydrogen generators might supply just one or two vehicles — such as a home electrolyzer — or they might supply hydrogen on-site for a 50- or 100-car fleet. Or a local steam methane reformer might supply several fleets within a given area.

The small-scale hydrogen appliance option essentially takes advantage of two very robust energy infrastructures: the natural gas pipeline system and the electrical power grid. The hydrogen would be produced where it is needed, instead of at a central facility, with no need for building any new fuel transportation infrastructure. While the hydrogen would initially cost more due to the poor economies of scale, at least one analysis has shown that small-scale hydrogen generators could be cost-effective, particularly if produced in large quantities.

If successful, these small-scale hydrogen generators could grow in parallel with the hydrogen vehicle market. The gas industry could plan its investments to match the growth of the hydrogen vehicle industry, and the automobile manufacturers could ramp up their production, confident that a hydrogen supply would be available when and where needed, thereby significantly reducing the risks for both industries.

Early hydrogen-fueled vehicles will necessarily be confined to local areas due to lack of fueling facilities. Hydrogen-fueled vehicles would be sold to fleets and would also be used by commuters within urban areas plagued by air pollution. Since many families in the developed nations have two or more vehicles, they can designate one clean hydrogen car for in-city use and one for the relatively rare long-distance trips. Once islands of hydrogen fueling stations are in place, the next step would be to install hydrogen-fueling stations along major highways. These hydrogen-corridor stations would then open up the long-distance market for hydrogen-fueled vehicles.

The appropriate combination of hydrogen infrastructure options will depend strongly on the type of hydrogen onboard storage. If the vehicles store gaseous hydrogen, all four infrastructure options are available. If the vehicles store liquid hydrogen, then the small-scale hydrogen generator option is eliminated, and the early hydrogen vehicles would have to be supplied by excess capacity from existing liquid hydrogen plants. Economics will ultimately decide between gaseous or liquid onboard hydrogen storage, assuming that the public perceives either option to be equally safe.

Proponents of onboard liquid hydrogen contend that liquid hydrogen has fewer risks, but at least one merchant gas supplier considers liquid hydrogen handling to be more complex, with a higher safety risk. At the present time, however, no U.S. automobile manufacturer is actively developing onboard liquid hydrogen storage systems. General Motors is pursuing methanol, Ford is assessing both gaseous and liquid hydrogen onboard storage, and Chrysler initially evaluated gaseous hydrogen but is now considering liquid hydrocarbon fuels with an onboard fuel processor to make hydrogen. BMW is the only major automobile manufacturer actively developing and testing liquid hydrogen passenger vehicles.

Recommended Action Items

1. *Onboard Liquid Hydrogen vs. Gaseous Hydrogen Evaluation*

A thorough systems analysis is required to objectively compare the projected costs, performance, and safety aspects of onboard gaseous versus onboard liquid hydrogen storage for hydrogen-ICE hybrid electric and fuel cell passenger vehicles, including the complete fuel infrastructure and vehicle implications.

2. *Hydrogen Infrastructure Demonstration Project*

NHA members should consider a hydrogen infrastructure development and demonstration project (presumably including government cost-sharing) that would analyze and compare three options for providing cost-competitive gaseous hydrogen for early hydrogen vehicles:[12] a liquid hydrogen storage and vaporizer dispensing system using trucked-in liquid hydrogen from existing merchant hydrogen plants; a small-scale electrolyzer and compressor dispensing system; and a small-scale steam methane reformer (or other appropriate fossil fuel processor), gas cleanup, compressor, gaseous storage and dispenser system.

3. *Identify Prime Hydrogen Vehicle Demonstration Sites*

The National Hydrogen Association, as a service to its members and to other companies or organizations that may wish to participate in hydrogen vehicle demonstration projects, should assemble a list of appropriate hydrogen vehicle demonstration sites or regions, taking into account for each site the clean air incentives, any local or state clean air mandates, the local price of off-peak electricity, the local price of natural gas, the local price and availability of excess merchant hydrogen, the local renewable energy resources, the proximity of any centrally fueled vehicle fleets to those sources of excess merchant hydrogen, and, if possible, an assessment of the local fire marshall or regulatory agency regarding hydrogen vehicles.

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[12]We assume here that initial hydrogen-fueled vehicles in the U.S. will use gaseous hydrogen, since no U.S. company nor the DOE is actively developing liquid hydrogen storage systems at this time, although at least one company is assessing the use of liquid hydrogen. See the section below regarding onboard storage for recommendations on liquid onboard storage.

Overcoming the Safety, Codes, and Standards Barrier. Dealing with safety is in one sense more difficult than handling technical hurdles such as cost or infrastructure, since we must deal with both the reality and the perception of safety. A hydrogen system may be engineered to be far less risky than existing gasoline-powered vehicles, but, if the public (or the insurance industry) *perceives* a hydrogen vehicle to be unsafe, then the hydrogen energy industry will remain a dream. So we must deal with both the reality and the perception of safety.

Safety must be paramount in all hydrogen activities. The infant hydrogen energy industry cannot afford even one accident. Every project should be thoroughly scrutinized, preferably with a hazards review by recognized hydrogen safety experts, before construction begins. Technical safety issues — such as the development of fuel cell compatible odorants for hydrogen versus the use of hydrogen sensors and active ventilation, especially for residential garages — must be resolved.

Assuming that the hydrogen industry solves these technical issues, the question of public perceptions will remain. Education is the best antidote, and both DOE and the NHA have been active in promoting public education, most recently by supporting the Hydrogen 2000 documentary film project. These activities must continue to pave the way for the hydrogen energy industry.

The National Hydrogen Association has also taken the lead in establishing three separate groups to pursue developing codes and standards for gaseous hydrogen. (The International Standards Organization is currently developing codes and standards for liquid hydrogen vehicles.) These groups are modeled after the natural gas vehicle industry, covering onboard high pressure gas storage, the refueling connectors, and the refueling station itself.

Recommended Action Items

1. *Hydrogen Safety Review*

The National Hydrogen Association should recommend that all hydrogen energy projects be reviewed by an expert panel of hydrogen safety experts. While NHA does not have the resources to implement a formal Hydrogen Safety Review Board, the NHA should recommend appropriate hydrogen safety experts to potential hydrogen energy project managers. The U.S. Department of Energy should urge all DOE-funded demonstration projects to submit plans to a Safety Review Board for comment, recommended changes, and approval.

2. *Hydrogen Odorant Project*

The National Hydrogen Association Codes and Standards activity should determine whether it is feasible to develop U.S. Department of Transportation (DOT) standards for onboard storage of hydrogen that accepts electronic hydrogen sensors in place of the customary gaseous fuel ordorant, mercaptan. If the NHA concludes that odorants will be required by DOT, then the U.S. Department of Energy should fund a research project to develop fuel cell-compatible odorants for hydrogen, or means of removing conventional mercaptan ordorants on the way into the fuel cell.

3. *Home Garage Safety Analysis*

Industry should analyze and recommend the appropriate safety measures for hydrogen vehicles parked in home garages. The project should demonstrate the safe operation of hydrogen leak detectors, ventilation systems, and other remedies.

4. *Codes and Standards Development*

The U.S. Department of Energy should continue funding the NHA Codes and Standards development project (in addition to the odorant standard issue listed above).

5. *Public Education*

Both the National Hydrogen Association and the U.S. Department of Energy should continue their public education activities, since public acceptance of hydrogen as an energy carrier is essential for the hydrogen energy industry.

Overcoming the Onboard Storage Barrier. The onboard storage barrier is one of perception more than reality. There are two technically and economically feasible onboard hydrogen storage options for the private passenger vehicle: liquid hydrogen and compressed gaseous hydrogen storage. Both are acceptable, and both can be designed into full-performance passenger vehicles. Other hydrogen storage options suggested over the years are either too immature, too heavy, or too costly, but the transportation industry only needs one viable hydrogen storage and fuel supply option. Other hydrogen storage options including metal hydride or carbon adsorption systems are available for larger vehicles such as trucks or buses, or in other niche applications that do not have the weight limitations or range requirements of conventional passenger vehicles.

The only significant disadvantage of high-pressure, compressed-hydrogen storage is large volume. The 5,000 psi hydrogen tank currently proposed may occupy three to four times the volume of the gasoline tank it replaces for the same range. But if the total power train system (fuel cell or hybrid internal combustion engine plus electric motor, gear box, and hydrogen storage) can fit into approximately the same space as the conventional power train (internal combustion engine, transmission, exhaust system, and gasoline tank), then a vehicle can be designed to meet the expectations of the driving public. The key is a ground-up vehicle design. The vehicle should be designed to accommodate the hydrogen-fueled power train, not the other way around.

A liquid hydrogen storage system occupies less space than one for gaseous hydrogen, but requires inherently more expensive hydrogen due to the cost of liquefaction. Liquid hydrogen also may suffer from boil-off — a vehicle parked for a week could lose substantial fuel — but proponents of this approach claim to have reduced boil-off to acceptable levels.

Recommended Action Items

1. *Compressed Hydrogen Tank Qualification Tests*

High pressure (5,000 psi) hydrogen fiber-wrapped composite tanks must be qualified under NGV-2 tests (suitably modified for hydrogen) for use on public roads.[13] The National Hydrogen Association, working with the automobile manufacturers and tank manufacturers, should take the lead in qualifying these tanks for onboard vehicle use.

2. *Compressed Hydrogen Connector Tests*

Similarly, high-pressure connectors for storage tanks must be qualified under (modified) NGV-1 certification tests. Again, the NHA, working with automobile manufacturers and connector manufacturers, should take the lead in qualifying these connectors for public motor vehicle use.

3. *Onboard Liquid Hydrogen Storage*

If the liquid versus gaseous hydrogen systems analysis (see hydrogen infrastructure action items above) shows that onboard liquid hydrogen could be competitive with a gaseous hydrogen transportation system, *and* if an automobile company indicates that liquid hydrogen onboard storage is a serious option, then NHA members should work with the automobile companies to develop an appropriate liquid hydrogen-dispensing demonstration system.

Overcoming Cost Barriers. Much progress has been made in reducing the cost of key hydrogen energy system components, such as fuel cells and storage tanks, through ongoing research and development projects. Several studies under the DOE Hybrid and Fuel Cells for Transportation Programs with the automobile manufacturers have shown that complete fuel cell systems for vehicles could be nearly cost-competitive with conventional vehicles in large-volume mass production. Other studies have shown that hydrogen used in fuel cell vehicles and possibly in hydrogen-ICE hybrid vehicles could be competitive with gasoline per mile driven under appropriate circumstances. But much work remains to firm up these paper calculations, both for hydrogen vehicles and for the hydrogen infrastructure.

Building the small-scale hydrogen generators recommended above under the infrastructure program would help to refine cost estimates for producing hydrogen in small quantities specifically for the transportation market.

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[13]Fiber-wrapped composite tanks with a safety factor of 2.25 have been approved for use with natural gas vehicles at 3,600 psi by the U.S. Department of Transportation. Certification at 5,000 psi should be routine, but these stronger tanks would probably have to pass the natural gas vehicle testing procedures (NGV-2) before DOT would consider certification.

One essential element of this commercialization plan is to establish reliable estimates for hydrogen energy system component costs in large-volume mass production. Today's costs are almost irrelevant. For example, current low volume, virtually hand-manufactured fuel cells may cost $3,000/kW or more. Yet several studies have predicted mass production costs of less than $50/kW for fuel cell systems, given their relative simplicity and low-cost materials (now that platinum loadings have been reduced to acceptable levels). We need to substantiate these estimates and extend the analysis to other hydrogen components, including onboard storage tanks, peak power augmentation devices, etc. Fortunately, the other major fuel cell vehicle and hydrogen-ICE hybrid vehicle components — such as electric motors, controllers, and peak power augmentation devices — are being developed under other DOE and industry programs for battery-powered electric vehicles. The fuel cell vehicle program must keep abreast of the latest developments in electric vehicle components.

Similarly, the mass production costs for the small-scale hydrogen appliances must be developed. Some estimates have been made for small-scale electrolyzers and small-scale steam methane reformers, but this work needs to be scrutinized by industry and extended to other infrastructure components including low-volume, high-pressure hydrogen compressors, gas cleanup devices, stationary storage tanks, and dispensing and safety equipment.

Recommended Action Items

1. *Continued Mobile Fuel Cell and Other R&D*

Research and development of key hydrogen transportation components should continue, with special emphasis on reducing manufacturing costs in large production volumes, including complete fuel cell systems, hydrogen-ICE hybrid systems, onboard hydrogen storage systems, stationary small-scale electrolyzers and steam-methane reformers, stationary hydrogen compressors, and hydrogen dispensing and safety equipment.

2. *Large Manufacturing Cost Estimation*

Industry should take the lead in determining the costs of hydrogen vehicle components in large volume mass production, including hydrogen-ICE hybrid vehicle systems, fuel cell systems, onboard hydrogen storage, onboard peak power augmentation, stationary small-scale steam-methane reformers and electrolyzers, stationary compressors, stationary hydrogen storage systems, and dispensing and safety equipment. Since the current hydrogen merchant gas suppliers have no experience in mass production, however, NHA will have to rely on analyses from other related industries.

Overcoming the Return on Investment Barrier. The U.S. Department of Energy is currently funding a systems analysis project to begin making long-term estimates of industry return on investment (ROI) under various scenarios of hydrogen vehicle market penetration. Separate ROI estimates are being made for the gas industry and for the automobile industry. Ultimately, each company must meet its own economic criteria along with many other factors before deciding to enter the marketplace. But the transportation market requires two disparate industries — vehicles and fuel suppliers — to effectively make joint business plans for an entirely new technology.

Furthermore, the two industries have to be concerned with their bottom lines rather than the environment or oil imports, so the government needs to separately evaluate the societal impact of these hydrogen transportation market penetration scenarios. Hence the need for a coordinated systems analysis encompassing all three entities: vehicles, fuel supply, and society. Hopefully, the projections of ROI from these government-funded studies will be sufficiently credible and sufficiently profitable to entice the appropriate companies to make their own business plans and to then decide to participate in the hydrogen energy development program.

Recommended Action Items

Systems Analysis of Market Penetration Scenarios

Industry should conduct systems analyses of various hydrogen transportation market-penetration scenarios, including comparison with other alternative fueled vehicles designed to meet the same societal objectives. The NHA should assist in coordinating industrial peer review of these analyses.

Overcoming the Insurance Barrier. Lack of insurance has curtailed some recent hydrogen project activities and forced others to rely on self-insurance by large corporations participating in the project. Insurance may become even more difficult to obtain as the public is exposed to hydrogen. One key approach may be to interest one or more insurance companies to become involved with the hydrogen energy business as a hedge against global climate change. The insurance industry has been among the first to recognize the consequences of climate change, since their liabilities rise with each new, weather-related disaster. Some may be very interested in working with the hydrogen energy industry to pave the way for the Hydrogen Energy Economy.

Recommended Action Items

1. *Seek Insurance Company Partners*

The National Hydrogen Association should actively seek out one or more insurance companies and encourage them to become active in developing the hydrogen energy insurance business.

2. *Hydrogen Risk Assessment*

The National Hydrogen Association, working in conjunction with the insurance industry, should consider the application of the science of risk assessment to hydrogen energy systems.

Overcoming Fixed Power Plant Market Barriers

As discussed previously, the fixed power plant market has fewer barriers than the transportation market, but also fewer rewards in terms of meeting environmental and oil import objectives. The primary barriers are cost, low or uncertain return on investment, and, in the case of remote village power, financing for overseas projects. Many of the market entry barriers have already been addressed, since one manufacturer has placed more than 65 of its 200-kW fuel cell systems in operation around the world. Although this phosphoric acid fuel cell system may provide limited technological spin-off benefits for the automotive PEM fuel cells currently under development, many — if not all — of the codes, standards, and siting issues have been favorably resolved.

Overcoming Fixed Power Plant Cost and ROI Barriers. As with mobile fuel cell systems, government research is justified to reduce the cost of natural gas-powered fuel cell systems for utility applications, including both hardware development and systems analysis. Stationary fuel cells must be more durable than mobile fuel cells, although they experience far less vibration, shock, or temperature swings than their mobile counterparts. The stationary PEM fuel cell system also requires an inexpensive gas cleanup system that is not required in the existing commercial phosphoric acid stationary fuel cell system. Both the natural gas reformer and the gas cleanup system developed for this application will have direct benefits for small-scale hydrogen generators for the transportation market.

The stationary fuel cell system will be most economical if the customer can utilize the waste heat from the unit. Since these systems are small, silent, and nonpolluting, they can be located on the customer's site, offering the possibility of cogeneration (both heat and electricity can be supplied to the customer). Additional systems analysis may be justified to quantify the advantages of cogeneration in the distributed utility market. These analyses also would provide potential suppliers of stationary fuel cell systems with greater confidence in projecting adequate return on investments.

Recommended Action Items

1. *Stationary Fuel Cell R&D*

Research and development of stationary fuel cell systems should continue, with emphasis on appropriate steam-methane reformers and gas cleanup systems to drive fuel cell systems.

2. *Stationary Fuel Cell Systems Analysis*

The National Hydrogen Association should collect and disseminate relevant information regarding the conditions under which natural gas-powered PEM fuel cells could be advantageous for various classes of utility customers.

Overcoming Market Barriers to Remote Power Hydrogen Storage Systems. This hydrogen commercialization plan assumes that renewable energy system markets will grow substantially in the years ahead, primarily in the developing world or other remote areas away from an electrical power grid. As intermittent renewable energy systems grow, so will the demand for inexpensive energy storage. This plan calls for the parallel development of inexpensive hydrogen electrolyzers, stationary hydrogen storage systems, and fuel cells to regenerate electricity when needed. Three elements are recommended to overcome barriers to using hydrogen for off-grid applications: hardware development, systems analysis, and dissemination of hydrogen storage benefits to renewable energy system suppliers and others.

Since the largest market for remote hydrogen storage may be in developing countries, financing and maintenance may be difficult. Early demonstration projects should, therefore, be sited on more friendly territory, with greater access to capital and also better maintenance capability. Alaska has already been identified as a likely location, having many remote villages supplied by very costly diesel power. Other possible areas include resort islands, such as those in the Caribbean that can afford to pay for reliable power and value low-pollution alternatives. The growing ecotourism market may be a good avenue for transition village power systems.

Recommended Action Items

1. *Hydrogen Storage Systems Analysis*

Industry should initiate a systems analysis of hydrogen storage systems for remote village intermittent renewable power, identifying the conditions necessary for hydrogen storage to be cost-competitive with battery storage of electricity.

2. *Hydrogen Storage System R&D*

Industry should develop a remote hydrogen storage system (electrolyzer/storage/fuel cell) to be compatible with intermittent renewable energy systems (PV, wind, solar thermal, etc.).

3. *Remote Village Hydrogen Storage Demonstration Project*

NHA should coordinate a remote village hydrogen storage project in concert with an intermittent renewable energy project and appropriate international funding agencies. The NHA also should develop a catalog of likely sites for early renewable hydrogen storage demonstration projects, considering renewable energy availability (solar and wind) and local electricity prices (e.g., Alaska, resort islands, etc.).

Summary of the Hydrogen Commercialization Plan

The National Hydrogen Association hydrogen commercialization plan is based on the premise that hydrogen will eventually become the storage mechanism for intermittent renewable energy in a sustainable energy future. Hydrogen also will become the dominant energy carrier for transportation, even if it is initially produced from natural gas or other fossil fuels.

In the transition period, before fossil fuels become too expensive due to some combination of environmental damage or scarcity, hydrogen will be used only as an energy carrier when and where it is cost-effective. Government mandates or incentives can ease the transition to clean fuels like hydrogen for the short-term, but hydrogen must ultimately succeed in the marketplace on its own without any government involvement. The NHA hydrogen commercialization plan is a market-oriented approach, based on three market entry points:

- Hydrogen-powered vehicles,
- Natural gas-powered stationary distributed power generation, and
- Remote village renewable hydrogen storage.

The hydrogen-powered fuel cell vehicle, or possibly the hydrogen-ICE hybrid vehicle, are the only hydrogen markets that are projected to be cost-competitive or nearly cost-competitive with the existing fossil fuel alternative (gasoline-powered vehicles) while simultaneously offering major reductions in urban air pollution, oil imports, and greenhouse gas emissions. This economic advantage is due to the 2.0 to 2.7 times greater energy efficiency[14] of the fuel cell vehicle compared to the internal combustion engine, which more than overcomes the 30 percent energy loss when converting natural gas to hydrogen, and the 1.5 to 1.8 times greater efficiency for a hydrogen-ICE hybrid electric vehicle. No other near- or mid-term hydrogen application provides these advantages without assuming major increases in the cost of fossil fuels.

[14]On a lower heating value basis.

The natural gas-powered stationary fuel cell system also is projected to be cost-competitive with the alternative, especially for cogeneration applications where the customer utilizes the waste heat from the fuel cell. This fuel cell electrical generator does not have the same societal advantages as the fuel cell vehicle, since it does not reduce oil consumption. It does not reduce local air pollution or greenhouse gas emissions as much. But the stationary fuel cell has the advantage of helping to develop fuel cell technology, which may assist fuel cell vehicle technology. The natural gas-powered stationary fuel cell will help to reduce the manufacturing cost of steam-methane reformers and gas cleanup systems, both of which will be needed to supply hydrogen for the hydrogen vehicle market. This stationary application is, therefore, primarily a stepping stone to assist in the development of the primary market: the hydrogen-fueled vehicle.

The natural gas reformers that supply hydrogen to stationary fuel cells are sized to meet peak electrical demand. That means there is excess hydrogen production capacity at all other times. Integrating a stationary fuel cell with a hydrogen vehicle refueling station can be done with minimal added capital cost.

The remote village hydrogen storage system comes much closer to the hydrogen energy industry vision of all energy supplied by renewable energy. However, renewable energy is usually too expensive to compete head-on with fossil fuel generated power in the developed world. Although wind power is cost-effective in some areas, the electrical grid serves as the effective storage medium; hydrogen cannot compete with grid storage. In remote off-grid locations, however, batteries are currently the primary storage medium, with noisy and dirty diesel engines as backup. The delivered cost of diesel fuel is very high in some remote locations. The plan, therefore, calls for the development of hydrogen storage systems to compete with battery storage, starting in high-priced, off-grid markets, such as in Alaska or on resort islands. This market will become the true link to a renewable hydrogen future.

The hydrogen commercialization plan includes both long-term goals and short-term action items that will start us down the road toward the hydrogen energy industry. The most important short-term activity is the development and demonstration of a viable, cost-effective hydrogen fueling infrastructure. The automobile industry will not start mass-producing hydrogen vehicles until it is convinced that the hydrogen will be there when its customers drive up to the pump. We believe that some combination of the four elements of this hydrogen infrastructure development plan (hauled-in liquid hydrogen, small-scale steam-methane reformers and small-scale electrolyzers, fleet applications, and hydrogen corridors) will provide the necessary hydrogen infrastructure for hydrogen-fueled vehicles. The other two key action items are safety and business planning issues.

We have not had the resources to cost out this plan. It should be considered a skeleton, outlining the direction, with details to be filled in as a result of both NHA activities as well as through ongoing and newly proposed activities by the U.S. Department of Energy and its counterparts around the world.

Appendix F

ISO Proposals: Hydrogen and Hydrogen Blend Vehicular Systems, and Basic Requirements for Gaseous Hydrogen Vehcils (GVH) Fuel Containers

National Hydrogen Association

1800 M Street, NW
Suite 300
Washington, DC 20036-5802

Telephone 202 / 223-5547
Facsimile 202 / 223-5537
E-mail: nha@ttcorp.com

March 7, 1997

Mr. James McCabe
American National Standards Institute
11 West 42nd Street
New York, NY 10036

Dear Mr. McCabe,

Attached are the National Hydrogen Association's proposals for the ISO TC 197 meeting in late May in Toronto, Ontario, Canada. There are two work items: *Hydrogen and Hydrogen Blend Vehicular Fuel Systems* and *Basic Requirements for Gaseous Hydrogen Vehicles (GVH) Fuel Containers* proposed for consideration in the meeting. As a member of U.S. TAG, I am submitting the following proposals through ANSI, the U.S. representative to ISO.

If you have any questions, please call me at (202)223-5547. Thank you for handling these items and your consideration in this matter.

Sincerely

Bob Mauro

Robert Mauro

cc: Chet Roberts
Comressed Gas Association

NEW WORK ITEM PROPOSAL	
Date of presentation	Reference number (to be given by secretariat)
Proposer	ISO/TC /SC N
Secretariat	

A proposal for a new work item within the scope of an existing technical committee or subcommittee shall be submitted to the secretariat of that technical committee or subcommittee with a copy to the Central Secretariat and, in the case of a subcommittee, to the secretariat of the parent technical committee. The proposal will be circulated to the P-members of the technical committee or subcommittee for voting, and to the O-members for information. The proposer may be a member body of ISO, the secretariat itself, another technical committee or subcommittee, an organization in liaison, the Technical Management Board or one of the advisory groups, or the Secretary-General. Guidelines for proposing and justifying a new work item are given in ISO Guide 26 (see extract overleaf).

The proposal (to be completed by the proposer)

Title of proposal

Hydrogen and Hydrogen Blend Vehicular Fuel Systems

Scope (as defined in 2.3.2 of part 3 of the ISO/IEC Directives)

See Attached

Purpose and justification (attach a separate page as annex, if necessary)

See Attached

Target date (indicate the date by which the availability of the International Standard is considered to be necessary)

Relevant documents to be considered

See Attached

Relationship of project to activities of other international bodies

TBD

Liaison organizations

TBD

Need for coordination within ISO and IEC

TBD

Preparatory work

- [ ] A draft is attached
- [X] An outline is attached and it will be possible to supply a draft by (date) ....
- [ ] It is not possible to supply either a draft or an outline
- [ ] Proposed project leader (name and address): ....

Concerns known patented items
(see part 2 of the ISO/IEC Directives)

[ ] yes [X] no

If yes, provide full information as annex

Signature of the proposer

Date of circulation	Closing date for voting	Signature of the TC or SC secretary

FORM 4 (ISO)

See overleaf

Proposer: The National Hydrogen Association through ANSI the U.S. representative organization to ISO

Title: Hydrogen and Hydrogen Blend Vehicular Fuel Systems

Scope: The standardization of design and installation of compressed hydrogen and hydrogen blend engine fuel systems on vehicles of all types, including aftermarket and OEMs and the service station from the point of on-site supply to the connection at the receiver.

Purpose and Justification:

The purpose of the standard is to standardize the design and installation of compressed hydrogen and hydrogen blend fuel systems on vehicles, including the dispensing service station, the connector to vehicle and vehicle fuel system.

Hydrogen fueled vehicles are being refueled and driven on public roadways across national boundaries. The lack of a consensus standard has caused and will continue to cause difficulties for vehicle developers, vehicle/fleet operators, refueling station developers/operators, and authorities having jurisdiction for hydrogen vehicle safety. It is expected that the proposed standard will reduce this problem.

The only factor that could hinder the general application of this standard is the lack of a standard for on-board containers that store compressed hydrogen at 5,000 psi.

The preparation of the standard is feasible and timely given the emergence of hydrogen prototype vehicles in Europe, the USA, and Japan. In addition connectors for transferring 5000 psi hydrogen gas are entering the commercial market. These activities lead to a desire to standardize the pressures, design and operation of the dispensing station, the refueling interface between the dispensing station and the vehicle, and the vehicle fuel system. This standard can be issued as a separate standard or if desired combined with other standards on vehicular fuel systems. It may also be broken up into three standards (vehicle fuel container will be dealt with in another submittal):

Dispensing station
Connector
Vehicle fuel system.

Suggested time to complete the work item is 4 years.

The benefits to be gained: Assurance that the on-board fuel system can be compatible with the connector and dispensing system. This allows the vehicle fuel system to be refilled any where in a reliable and safe manner. This will become increasingly important as the corridor concept develops in Europe, the USA and Japan.

It is likely that this standard will have to harmonized with each nation's vehicle fuel system, connector, and service station standards.

Relevant documents:

Available national documents

USA NFPA 30A
NFPA 50A
NFPA 50B
NFPA 70 (NEC)

Other countries' relevant documents To Be Determined (TBD)

Cooperation and liaison:

Appropriate ISO organizations TBD.

Preparatory Work:

An outline is attached
The NHA is willing to undertake the preparatory work.

Hydrogen Vehicular Fuel Systems

Contents

Annex C

Matrix for establishing the purpose of a proposal

Purpose of the proposed new work	Aspects to be covered in the standard(s)								
	Terminology, symbols, signs, designation	Characteristics	Sampling	Testing and inspection	Complementary requirements (labelling, packaging, storage, etc.)	Documentation, e.g. to accompany the product	Other aspects and requirements		
Mutual understanding and communication	XXXXXXXXX								
Safety, health, protection of environment	XXXXXXXXX	XX							
Achievement of interchangeability or interface or compatibility provisions	XXXXXXXXX	XX							
Performance, function, quality	XXXXXXXXX	XX							
Economy of energy and raw material									
Variety control (rationalization)									
Consumer protection	XXXXXXXXX	XX							
Other purposes									

Characteristics

a. Service station
- Siting
- Container installation
- Overpressure protection
- Pressure regulators
- Pressure gauges
- Piping & hoses

b. Connector design
- Pressure rating
- Material compatibility
- Shape
- Finish
- Leak tightness

c. Vehicle fuel system
- Container
- Venting
- Piping
- Valves
- Pressure gauges
- Pressure regulators
- Fuel connection
- Wiringinstallation
- Labeling
- System testing
- Maintenance and repair

NEW WORK ITEM PROPOSAL	
Date of presentation	Reference number (to be given by secretariat)
Proposer	ISO/TC /SC N
Secretariat	

A proposal for a new work item within the scope of an existing technical committee or subcommittee shall be submitted to the secretariat of that technical committee or subcommittee with a copy to the Central Secretariat and, in the case of a subcommittee, to the secretariat of the parent technical committee. The proposal will be circulated to the P-members of the technical committee or subcommittee for voting, and to the O-members for information. The proposer may be a member body of ISO, the secretariat itself, another technical committee or subcommittee, an organization in liaison, the Technical Management Board or one of the advisory groups, or the Secretary-General. Guidelines for proposing and justifying a new work item are given in ISO Guide 26 (see extract overleaf).

The proposal (to be completed by the proposer)

Title of proposal

Basic Requirements for Gaseous Hydrogen Vehicles (GVH) Fuel Containers

Scope (as defined in 2.3.2 of part 3 of the ISO/IEC Directives)

See Attached

Purpose and justification (attach a separate page as annex, if necessary)

See Attached

Target date (Indicate the date by which the availability of the International Standard is considered to be necessary)

Relevant documents to be considered

See Attached

Relationship of project to activities of other international bodies

TBD

Liaison organizations	Need for coordination within ISO and IEC
TBD	TBD

Preparatory work

- [ ] A draft is attached
- [x] An outline is attached and it will be possible to supply a draft by (date) ____________
- [ ] It is not possible to supply either a draft or an outline
- [ ] Proposed project leader (name and address): ____________

Concerns known patented items (see part 2 of the ISO/IEC Directives)	Signature of the proposer
☐ yes ☒ no If yes, provide full information as annex	

Date of circulation	Closing date for voting	Signature of the TC or SC secretary

See overleaf

Proposer: The National Hydrogen Association through ANSI, the U.S. representative organization to ISO

Title: Basic Requirements for Gaseous Hydrogen Vehicles (GVH) Fuel Containers

Scope: The proposed standard specifices material, design, manufacture and testing of refillable type GHV2 containers (1,000 liters or less) intended only for the storage of compressed hydrogen for vehicle operation.

Purpose and Justification: The purpose of the proposed standard is to provide a standard for designers and manufacturers of on-board hydrogen fuel tanks made of various materials used to contain the fuel for vehicle operating on gaseous hydrogen.

Concern has been expressed about the safety in having high pressure gaseous storage tanks on-board vehicles. Recent failures by two CNG tanks on vehicles in the United States has made concerns about tank failure more acute.

The main interest that might benefit from proposed standards are: tank manufacturers, vehicle manufacturers, service/repair technicians and hydrogen vehicle operators.

The vehicle industry has a global market. Vehicles and parts are rountinely produced in one country and installed in vehicles, sold or operated in another. Standardization of on-board hydrogen storage tanks will allow containers and vehicles with containers to be shipped, sold and, in the case of vehicles, operated safely and reliably world-wide.

The preparation of the proposed standard is feasible and timely, since gaseous hydrogen fueled vehicles are beginning to be produced and demonstrated. There is a need to qualify containers for on-board hydrogen storage in a manner that allows for a range of lighter weight and nonmetalic materials as well as steel hydrogen containers. If necessary, a separate standard could be issued for each type of container.

Suggested time to complete the work item is 4 years.

The benefits to gained from this standard are minimum performance standards for any type of container covered by the standards at uniform pressures. The will enable on-board storage containers to be produced in one country and installed in another, uniformity for the testing , acceptance, servicing and operation of vehicles with gaseous hydrogen containers.

Relevant documents

Available National Documents

– USA ASME Boilers and Pressure Vessels Section VIII
NGV2
NFPA 70 (NEC)

Other countries' relevant documents To Be Determined (TBD).

Cooperation and Liaison:

TBD

Preparatory Work:

The NHA is willing to undertake preparatory work.

Basic Requirements for Gaseous Hydrogen Vehicle (GHV) Fuel Containers

Contents

Chapter 18 Design Qualification Tests

18.1 General
18.2 Test Requirements
18.3 Ambient Cycling Test
18.4 Environmental Test
18.5 Hydrostatic Burst Test
18.6 Composite Flaw Tolerance Test
18.7 Drop Test
18.8 Bonfire Test
18.9 Accelerated Stress Rupture Test
18.10 Penetration Test
18.11 Permeation Test
18.12 Natural Gas Cycling Test
18.13 Qualification Test Results

Annex C

Matrix for establishing the purpose of a proposal

Purpose of the proposed new work	Aspects to be covered in the standard(s)								
	Terminology	Materials of Construction	Inspection Requirements	Pressure Cycling	Service Pressure and Temperature	Mounting Assembly	Gas Permeation	Documentation	Labeling
Mutual understanding and communication	X	X	X	X	X			X	X
Safety, health, protection of environment		X	X	X	X	X	X	X	X
Achievement of interchangeability or interface or compatibility provisions		X			X	X			
Performance, function, quality		X	X	X	X		X		
Economy of energy and raw material		X			X				
Variety control (rationalization)					X	X			
Consumer protection		X			X	X			X
Other purposes									