Proceedings

National Hydrogen Energy Roadmap Workshop

Washington, DC, April 2-3, 2002

PROCEEDINGS
NATIONAL HYDROGEN ENERGY ROADMAP WORKSHOP

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On April 2-3, 2002, more than 200 participants representing hydrogen energy industries, academia, environmental organizations, federal and state government agencies, and National Laboratories met for a National Hydrogen Energy Roadmap Workshop in Washington, DC. (A list of the participants can be found at the end of this document.) During the workshop they discussed the actions that need to be taken in order to reach the hydrogen vision that was identified during the National Hydrogen Vision Meeting in November 2001. The intent was to identify the most important barriers and needs that should to be addressed in order to achieve the vision, the time frames for the top priority research and development and other efforts, and the respective roles of industry, government, universities, and National Laboratories in dealing with these issues.

This document is a summary of the proceedings from that meeting. It captures the comments and ideas that were exchanged, and summarizes the major themes that were expressed throughout the workshop. There will be a forthcoming national roadmap document that will be released shortly.

SECTION 1
OPENING PLENARY SESSION

Welcome and Opening Remarks

Robert Dixon, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

- Welcome to the National Hydrogen Roadmap workshop. We appreciate the time you've taken out of your busy schedules to be here with us today. Thank you.
- I would like to introduce Under Secretary of Energy Robert G. Card. Mr. Card is going to provide some opening remarks. Mr. Card attended the National Hydrogen Vision Meeting held in November and is a strong supporter of our efforts in this arena.

Robert Card, Under Secretary, U.S. Department of Energy

- Welcome. Thank you in advance for your hard work and participation in this Roadmap meeting.
- Science and energy research functions are driven by this process…not paper pushing.
- Since the National Hydrogen Vision Meeting in November, we have announced the FreedomCAR initiative.
- Since the November meeting, I have become more familiar with the technology; I recently had the opportunity to visit a hydrogen pipeline.
- We need to keep the investment criteria in mind. We are now beginning the FY04 budgeting process. We need to ask the following questions: 1) How many tons of carbon are we going to displace? What will be the cost?
- When considering hydrogen, we need to keep price competitiveness in mind. We must also remember that hydrogen is a long-term resource.
- Current issues for the Administration include climate change, energy supply, and energy security. In addition, there are many other budget issues under consideration.
- The outputs of the November Vision Meeting were instrumental in our decision to launch the FreedomCAR initiative. I would like to see something similar to the FreedomCAR initiative come out of this National Hydrogen Energy Roadmap Workshop.

Legislative Update on Hydrogen-related Legislation

Jeff Serfass, President, National Hydrogen Association

- Hydrogen Future Act – Amendments to Matsunaga Hydrogen R, D&D Act of 1990.
- House Energy Bill: HR 4, §2205, Hydrogen Research and Development, $40-60 million for R&D from 2002-2006, $20-40 million for demonstrations; advisory committee by National Academies of Science and Engineering
- Senate Energy Bill: Energy Policy Act of 2002, Title XII, Subtitle B, §1223, Hydrogen R&D, $65-80 million for R&D from 2003-2006, $25-40 million for fuel cell and hydrogen demonstrations; includes E&O, villages and foreign economic development; interagency task force to plan for development and demonstrations in Federal buildings and buses/fleets
- Agriculture bill S. 1731: Energy Title, §388H, Hydrogen and Fuel Cell Technologies Program; includes demonstration of hydrogen technologies and fuel cell technologies in farm, ranch, and rural applications; includes studies of technical, environmental, and economic viability in farm, ranch, and rural applications, of innovative hydrogen and fuel cell technologies not ready for demonstration; $5 million per year through 2006
- Energy Tax Incentives Act of 2002 S. 1979: Title II, Alternative Motor Vehicles and Fuels Incentives, $4 thousand for fuel cell cars, $10-40 thousand for larger vehicles, economy adders, $1-30 thousand for refueling property
- More Fuel Cell Titles: Energy Bills—Fuel Cell Bus Development and Demonstration Program, Clean Green School Bus Act, Alternative Fuel Vehicle Act, Federal Cost Sharing in Demos and Fuel Infrastructure
- 2003 Appropriations?: EE Hydrogen Research $39.9 million, + 37%, EE Transportation $275.7 million, -9% with $150 million redirection from FreedomCAR, Fuel Cell research throughout DOE—EE Transportation $50 million, EE Buildings $75. million, EE Power Generation $49.5 million (-15%), FE Carbon Sequestration $54 million, +67%, EE Biomass, and other Renewables

Presentation on the Integration of Activities at the Department of Energy

Steve Chalk, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

- We need a "business case" for expanding the use of hydrogen.
- The Department's current research on hydrogen production, storage, conversion, etc. will impact the next 20 years
- I'm hoping that this and other meetings will help guide us in the right directions.

Presentations on the Purpose and Goals of the Vision and Roadmap Process, and this Workshop

Tex Wilkins, Roadmap Leader, U.S. Department of Energy

- We have more than 200 people here today representing about 100 organizations.
- We all need roadmaps. For example, the Declaration of Independence was a roadmap that was written more than 200 years ago.
- As you know, the Hydrogen Vision meeting was held in November. Fifty-three people attended that meeting, and out of it came the Hydrogen Vision document.
- Today we have six areas that we will be focusing on: production, delivery, storage, energy conversion, applications, and public education and outreach. There will also be an integration group whose job it will be to incorporate all of the important ideas from each of the six areas.
- Roadmap chapters will ultimately be written by industry and university representatives. We envision that each chapter will be 4-5 pages and hope for a good draft by the end of May and a final draft sometime in June.
- Now I would like to introduce the roadmap leaders:
  - Energy Conversion - *Mike Davis, Avista Labs*
  - Delivery - *Art Katsaros, Air Products & Chemicals*
  - Applications - *Frank Balog, Ford Motor Company*
  - Storage - *Alan Niedzwiecki, Quantum Technologies*
  - Production - *Gene Nemanich, Chevron Texaco Technology Ventures*
  - Public Education and Outreach - *Jeff Serfass, National Hydrogen Association*
  - Systems Integration - *Joan Ogden, Princeton University*

Rich Scheer, Energetics, Inc.

- We really appreciate your being here and we've developed a facilitation game plan that should keep you very busy over the next two days.
- Recently there have been several U.S. Department of Energy-sponsored meetings related to H_2 and fuel cells: the Hydrogen Vision meeting, the Fuel Cell Report to Congress meeting, and the Fuel Cells for Building meetings. In your deliberations over the next several days it is important that you try to tie all of these events together. Many of you were involved in those other meetings. Please remember that you are not here to "reinvent the wheel."

Section 2

Hydrogen Production Breakout Session

- **Barriers:** What are the barriers that interfere most with achieving the vision?

- **Needs:** What are the most important needs to undertake between now and 2030 to address the barriers and achieve the vision?

- **Top needs and next steps:** What are the top priority needs, including their milestones and dates, primary funding entities, and next steps to addressing them?

Participants:

Name	Organization
Mark Ackiewicz	Technology & Management Services, Inc.
Arvind Atreya	University of Michigan
David Bartine	Kennedy Space Center
Gottfried Besenbruch	General Atomics
Mel Buckner	Savannah River Technology Center
Wilson Chu	Johnson Mathey Fuel Cells
Anthony Cugini	National Energy Technology Laboratory
Gregory Dolan	Methanol Institute
Kellye Eversole	Eversole Associates
Alexander Fridman	University of Illinois
Leo Grassilli	Department of the Navy, ASN (I&E)
Neville Holt	Electric Power Research Institute
Alan Johnson	ZECA Corporation
Dan Keuter	Entergy Nuclear, Inc.
Joe Klimek	Startech Environmental Corporation
Ravi Kumar	General Electric
Jay Laskin	Teledyne Energy Ssytems, Inc.
William Lewis	ExxonMobil Refining & Supply Co.

Participants:

Name	Organization
Ted Lima	Hamilton Sundstrand
Gary McDow	Air Liquide America
Gene Nemanich	ChevronTexaco Technology Ventures
Edson Ng	QuestAir Tehnologies, Inc.
Michael Nicklas	Innovative Design
Richard Noceti	National Energy Technology Laboratory
Manuel Pacheco	PDVSA-Citgo
Ken Schultz	General Atomics
Surindar Singh	Alberta Energy Research Institute
Andrew Stuart	Stuart Energy Systems
Chris Sutton	Air Products & Chemicals Inc.
Satish Tamhankar	BOC Group
David Tsay	Ztek Corporation, West Coast Office
John Turner	National Renewable Energy Laboratory
Robert Walker	Wexler & Walker Public Policy Associates
Kyle Wetzel	K. Wetzel & Co. Inc.

Facilitator: Ross Brindle, Energetics, Inc. (assisted by Tracy Carole)

BARRIERS – PRODUCTION
(✪ = Most Critical Barrier)

FEEDSTOCKS	PERCEPTION	POLICY	MARKETS	TECHNOLOGIES	COST
• Finite amount of fossil fuels ✪ • SMR at large scale will deplete North American natural gas resources ✪✪✪✪ • Feedstock impurities • Limited availability of energy source materials (relative lack of renewables and abundance of non-renewables) •	• Public perception and policy discouraging anything nuclear leads to restrictive regulations ✪✪✪✪✪✪✪ • Limited public perception and acceptance of hydrogen as safe limits sites for hydrogen production ✪✪ • Lack of understanding of why hydrogen research should be funded with public funds ✪ • Promising too much without results has eroded credibility	• Lack of joint government-industry efforts to demonstrate cost-effective hydrogen production ✪✪✪✪✪✪✪✪✪✪✪✪✪✪ • Lack of RD&D funding; difficulties breaking into constituencies ✪✪✪✪✪✪✪✪✪✪✪ • Lack of policy to reward non-pollution and/or tax pollution source ✪✪✪✪✪✪✪✪✪✪ • Lack of codes and standards ✪✪✪✪✪ • Societal costs are not properly accounted for ✪✪✪✪✪ • Nuclear restrictions ✪ • Permitting • Lack of clear leadership	• Lack of market pull ✪✪✪✪✪✪✪✪✪✪✪✪✪✪ • Market development is not occurring in steps with costs ✪✪✪✪✪✪✪✪✪✪ • Lack of definition of final product (type of hydrogen to produce) ✪✪✪✪✪✪✪✪✪ • uncertainties in distribution methods create uncertainties in production • Lack of support for early adopter markets for advanced distributed systems ✪✪✪✪✪✪✪✪✪ • Lack of non-traditional hydrogen demand ✪ • Intermediate customers have not been identified and engaged • these technologies may not offer large benefits but can enable the transition to hydrogen economy	• Lack of cost-effective, environmentally benign carbon sequestration methods ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ • Inadequate materials (catalysts, adsorbents, refractories, membranes) ✪✪✪✪✪✪✪✪ • Lack of demonstrated technology to mass-produce hydrogen ✪✪✪✪✪✪✪ • Lack of separation technology to produce hydrogen of suitable purity and quantity ✪✪✪✪✪✪ • Lack of technology to use waste head for hydrogen production ✪ • Difficulties overcoming existing infrastructure to enable hydrogen economy ✪ • Lack of concerted effort towards solar-based water dissociation methods for hydrogen production	• Hydrogen production is not profitable ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ • production, sequestration, energy source, life cycle costs, etc. are too high • Lack of cost targets to develop a business case ✪✪✪✪✪✪ • Cost of electricity and upstream emissions hinder electrolysis ✪✪✪✪ • High capital costs and low efficiency of hydrogen production relative to alternatives ✪ • Lack of understanding of benefits of different investment magnitudes ✪

RD&D Needs – Production (1 of 2)

(✪ = Most Critical to Realizing the Vision; ◆ Most Critical Near-Term Need)

Time Frame: (N =2002 = -2010; M = 2010-2020; L = 2020-2030+)

Lead (capital letters) and Supporting (lower-case letters) Roles: (I = Industry; G = Government; U = Universities; NL = National Labs)

Electrolysis	Thermal Cycles	Carbon/Water	Advanced Production Techniques	Crosscutting Process Technologies
• Higher efficiency, lower cost electrolysis (N; I) ✪✪✪✪✪✪✪ • Develop 900ºC electrodes and membranes for use with present nuclear off-peak ◆ • Develop techniques to use seawater as feedstock for electrolysis (desalination or direct feed)	• Demonstrate hydrogen production from nuclear power by thermochemical process ✪✪✪✪✪✪✪✪✪✪◆◆◆◆ (N; I, NL, g u) • sulfur and iodine PDU, research other cycles ✪✪◆◆◆◆ • Address kinetics and materials questions ✪✪◆◆◆◆ •	• Develop economic, scalable carbon capture and sequestration techniques (N-L; I, nl, u, g) ✪✪✪✪✪✪◆ • reduce cost of CO2 capture by 2/3 or more ✪✪✪✪✪ • membranes, catalysts, mineral carbonation, and pilots are needed ✪✪✪✪◆◆ • Distributed production via small-scale reformers (N; I, U, NL, g) ◆◆◆◆◆◆ • Improved and integrated refinery processes for hydrogen production (N-L; I) ✪✪✪✪◆◆ • Develop improved gasification processes (N; I, U, NL, g) ✪✪✪◆ • fuel flexibility for feedstocks ✪✪✪✪✪✪ • Hot gas clean-up for coal • Develop methods for higher oxygen concentration to influence CO_2 purity during carbon sequestration	• Research on hi-temperature direct conversion of water to hydrogen (thermal, solar, electric) – need rapid separation technologies on nano-scale time frames (M-L; NL, U, g) ✪✪✪✪✪✪✪✪✪✪◆ • More research into advanced "carbon-free" production processes ✪✪✪✪✪ • genetic engineering of biological-based photolytic processes ✪ • Develop lower-cost materials with longer lifetimes for semiconductor-based photolytic processes ✪ • develop nanotechnology production and storage capabilities ✪✪✪ • Develop and demonstrate methods to produce hydrogen by heat directly • nuclear – radiolysis • solar – plasma	• Improved separation and purification methods and materials ✪✪✪✪✪✪✪✪✪✪✪✪✪✪◆◆◆◆◆ • membrane separation of carbon and water • economical, scalable hydrogen separation at desired purity • Design for hi-volume mass production ✪✪✪✪✪ • Production from lowest cost feedstocks ✪✪✪◆◆ • Eliminate use of precious metals ✪✪✪✪ • Interconvertability of hydrocarbons and hydrogen ✪✪✪✪ • use carbon as a hydrogen carrier • on-board reformers; use CO_2 in atmosphere • Develop analysis tools to understand different production schemes ✪✪ • Develop improved materials (catalysts, hi-temperature, containment) ✪✪ • Develop direct hydrogen production processes with minimal steps ✪ • Develop hydrogen detection technology • Apply low-cost processes (e.g., semiconductor processes) to hydrogen generation and production

RD&D Needs – Production (2 of 2)

(✪ = Most Critical to Realizing the Vision; ◆ = Most Critical Near-Term Need)
Time Frame: (N = 2002-2010; M = 2010-2020; L = 2020-2030+)
Lead (capital letters) and Supporting (lower-case letters) Roles: (I = Industry; G = Government; U = Universities; NL = National Labs)

Hybrids	Demonstrations	Policy
• Capture synergies between products and technologies ✪✪✪✪✪✪ • plasma processes and plasma catalytic processes • hybrid fuel sources • Innovative technologies for hydrogen production to improve cost and availability (cross-fertilization of low-cost technology to create hybrid systems) • □□□□ • Couple hydrogen production with other system uses (e.g., cogeneration) ✪	• Technology demonstration of processes that can show the potential for technical and economic viability (N; I, G, u, nl) ✪✪✪✪✪✪✪✪✪✪✪✪◆◆◆◆◆◆◆◆◆◆◆◆◆ • Establish an industrial-scale testing facilities to develop new concepts (N, NL, U, g, i) ✪✪✪◆◆◆◆ • Simultaneous demonstration of best available technologies ✪✪✪ • Address transition technical issues by forming halfway houses where existing systems can be used ◆◆ • Demonstrate on-demand hydrogen generation (vehicle under different conditions, fueling stations) ✪ • Establish a national facility to test the system integration issues with components ◆	• Implement the national vision and garner government support for the hydrogen economy by 2020 (N; G, I) ✪✪✪✪✪✪✪✪◆◆◆◆◆◆◆ • we have the vision, we need the mission • Allocate significantly more public and private resources for applied research and demonstrations (N; I, G, nl) ✪✪✪✪✪✪✪✪✪✪◆◆◆◆◆◆◆ • people, funding, and facilities • Implement an integrated environmental policy to reward non-polluters and/or tax polluters based on a cap and trade system (N; G) ✪✪✪✪✪✪◆ • Develop economic modeling and policy strategies ✪✪✪◆ • Create a "Hydrogen Valley" like Silicon Valley to foster cross-fertilization of ideas and resources ✪✪◆◆ • Develop codes and standards for interchangeability for fittings, home safety, etc. ✪✪◆ • Define limited set of final products ✪✪◆ • Establish academic programs to train next generation researchers ✪✪ • Understand hydrogen's role and worth in energy markets, and its environmental and health impacts

NINE MOST WANTED - PRODUCTION

TOP-PRIORITY NEED	BRIEF DESCRIPTION OF THE NEED	KEY MILESTONES AND DATES	PRIMARY FUNDING ENTITIES	NEXT STEPS
• Technical demonstration by process that can show the potential for technical and economic viability	• Codes and standards that apply to all production processes, including safety • Demonstration projects to take place in public venues to promote public acceptance	• 2 years: establish codes and standards across all production techniques • 5 years: at least one demonstration "fair" in each major metro area	• Industry, related industrial organizations • Government co-funding	• Establish venue for government and industry to work together • Begin working with local governments to break down barriers to implementing demonstration projects
• Develop economic, scaleable carbon capture and sequestration techniques	• Cost reduction for capture • New methods for low-concentration capture • Demonstration • Validation for performance	• 2007: Demonstrate geological sequestration • 2010: Demonstrate mineral sequestration • 2010: Demonstrate three technologies • 2010: Reduce cost of high-concentration capture by 50% • 2020: Consider demonstrating ocean sequestration • 2030: Demonstrate low-concentration capture	• Government – DOE support, low-concentration capture • Industry – high-concentration capture • Sequestration – Work: NL:I 50:50; Funding: G:I 75:25 • High-concentration capture – work: NL:I 50:50; Funding: I:G 60:40 • Low-concentration capture – work: NL:U 50:50; Funding: G:I 75:25	• Conduct demonstrations of sequestration techniques
• Develop improved separation and purification methods and materials	• Economical gas separation technologies that are appropriate to hydrogen application and production method	• 2007: demonstrate hydrogen separation from mixed gas at 30% below current cost • 2007: demonstrate oxygen separation from air at 30% below current cost • 2015: demonstrate both at 50% lower cost	• Federal 80:20 for long-term research; 50:50 for demonstrations • Private, as desired	• Designate "gas separations technologies" as a separate program area equivalent in stature to hydrogen generation • Define performance targets for each application and production method

NINE MOST WANTED - PRODUCTION

TOP-PRIORITY NEED	BRIEF DESCRIPTION OF THE NEED	KEY MILESTONES AND DATES	PRIMARY FUNDING ENTITIES	NEXT STEPS
• Demonstrate hydrogen production from nuclear power by thermochemical process	• Utilities and refineries are risk-adverse. We need technical demonstration that thermochemical hydrogen production really works • Temperature greater than 800º C, integrated loop, continuous operation (greater than weeks)	• 2005: integrated laboratory loop of S-I cycle ($6M) • 2007: measure kinetics, materials, for Ca-Br cycle ($2M) • 2004: chemical data for HI-I2-H_2O equilibrium ($1M) • 2010: pilot plant (100 m3/hr) non-nuclear simulation ($30-50M) • 2012: pilot plant using NP 2010 ($20M)	• 2002-2010: DOE and some industry support • 2010-2012: (using 5% of NP 2010) 50:50 industry: government • 2012-2015 (using 100% NP 2010): 50:50 cost share • 2015+: Industry	
• Advanced direct production techniques • biological • photolytic • nanotechnology • nuclear • solar • hi-temperature	• Biological (dark process using biomass feedstock) – identify organisms for doing conversion, genomics for improved feedstock and microbes • Biological (solar) – genomics to understand the water splitting reaction center and the efficiency of conversion • Hi-temp direct (solar or nuclear) – separation technology fro hydrogen/oxygen separation at high temperatures (nanotechnology membranes) • Photolytic (semiconductor-based) – identification of materials for longer lifetimes (corrosion); quantum dots (nanotech)	• Biological – 2007: basic sequencing; 2020; functional control • Hi-temp – 2012: develop low-cost membranes for separation • Photolytic – 2012: materials identification	• Biological – NIH, DOE, NSF, USDA • Hi-temp – DOE, NSF, Industry, DOC • Photolytic – DOE, NSF, Industry	• Prioritize research needs by DOE, NSF, etc. • Support basic research to develop computational capabilities in support of these technologies
• Develop improved gasification processes; enable fuel flexibility for feedstock	• Cheaper oxygen, integration • Mixed feedstock handling (e.g., biomass, potcoke) • High-efficiency integration (heat management, IGCC) • Cheaper syngas production	• 2005: feedstock flexibility • 2005: optimization for cost reduction • 2005-2010: system integration • 2010: cheaper oxygen demonstration • 2020: integration with carbon sequestration (total system)	• Government-industry cost share	• Continue R&D with expanded scope (include other feedstocks)

Nine Most Wanted - Production

Top-Priority Need	Brief Description of the Need	Key Milestones and Dates	Primary Funding Entities	Next Steps
• Integrated environmental policy to reward non-polluters and/or tax polluters based on cap and trade system	• Integrated environmental policy (electric utilities, transportation, industrial, commercial, residential) • Set national cap for major pollutants: NOx, SOx, CO_2, etc., issue credits to match caps, and allow trading of credits	• 2004: national legislation is in place • 2010: legislation is implemented	• This policy can be a fund-generator. Funds collected can be directed to support energy R&D that reduced pollution, including hydrogen infrastructure	• Draft legislation
• Higher-efficiency, lower-cost electrolysis	• Electrolysis improvements include: • lower life-cycle hydrogen costs for application-specific uses considering the supply and source of electricity by improving efficiency, capital costs, and maintenance, etc. of complete system	• By 2010, for each target application: • improve efficiency • improve capital cost • improve total life-cycle costs • optimize	• Primary funding by industry • Goal-setting study by government assist	• For the major use/applications (e.g., transportation, stationary power, etc.) establish acceptable value of hydrogen • Establish price/value goals for electrolysis • Based on above, identify methods of achieving price and thus improvement needed • By 2002
• Distributed production using small-scale reformers	• Reduce cost • Improve reliability and safety • Develop codes and standards • Fuel flexibility • Materials development • Systems integration	• 2003: codes and standards in place • 2005: low-cost materials developed • 2005: demo multiple hydrogen refueling systems • 2007: demo multiple hydrogen energy parks • 2007: fuel flexible reformer	• Federal and state government • Industry • Incentives for high-efficiency and lower polluting technologies	• Support FreedomCAR • Integrate with stationary power (hydrogen energy park) • Flow down customer requirements to subsystem specs • Force introduction of high-efficiency, low-pollution systems

SECTION 3

HYDROGEN DELIVERY BREAKOUT SESSION

- **Barriers:** What are the scientific, engineering, environmental, institutional, economic, and market delivery barriers that interfere most with achieving the vision?
- **Needs:** What are the most important needs including research and development, demonstrations, analysis, policy, codes and standards, and outreach to address the barriers?
- **Top needs and entity roles:** What are the top needs, and which entities will address those needs?
- **Next steps:** What are the top priority needs including their descriptions, key milestones and dates, primary funding entities, and next steps?

Participants:

NAME	ORGANIZATION
Art Katsaros	Air Products
Neil Rossmeissl	U.S. Department of Energy
Rodney Carlisle	History Associates Incorporated
Helena Chum	NREL/HTAP
Ed Danieli	Praxair, Inc.
Bob Dempsey	Chevron Texaco Technology Ventures
Steve Fan	Ford
Rob Friedland	Proton Energy Systems
Bob Hawsey	ORNL
George Kervitsky	SENTECH
Ken Koyama	California Energy Commission
Mike Leister	Marathon Ashland Petroleum
Steve Melancon	Entergy Nuclear
Karen Miller	National Hydrogen Association
Marianne Mintz	Argonne National Laboratory
Jim Ohi	National Renewable Energy Laboratory
Venki Raman	Air Products
Paul B. Scott	Stuart Energy USA
Prentiss Searles	American Petroleum Institute
Brad Smith	Shell Hydrogen
Jeff Staser	Denali Commission (Alaska)
Sandy Thomas	H2Gen Innovations, Inc.
Gene Whitney	Office of Science & Technology Policy

FACILITATOR: Ed Skolnik, Energetics, Inc. (assisted by Christina TerMaath)

Hydrogen Delivery Barriers

(♦ = Number of Votes) Pertains to (P = pipelines, F = fueling stations, O= other, e.g., barge, rail, truck)

Scientific	Engineering	Environmental	Institutional	Economic	Market
Strategy on carrier media (P, F, O) ♦♦♦♦♦♦♦♦♦♦♦ ▪ Cost effective means of converting good H_2 carrier (methanol, ammonia) to H_2 ▪ Multiple infrastructures	Technical solutions to H2 dispensing are not mature (F) ♦♦♦♦	Lack of full social costing of alternatives (P, F, O) ♦♦♦♦♦♦♦♦♦♦♦	Codes and standards don't include H_2 (P, F, O) ♦♦♦♦♦♦♦♦♦♦♦♦♦♦ ▪ No clear definition of safety criteria ▪ National and international lack of harmonization	Transitional strategy missing (P, F, O) ♦♦♦♦♦♦♦♦♦♦♦♦♦ ♦♦♦♦♦ ▪ Chicken and egg dilemma, economics for fueling depend on volume ▪ Today's dollars, funding for 2020 projects ▪ Lack of investment strategy that matches developing market	Customer expectations (P, O, F) ♦♦♦♦♦♦♦♦♦ ▪ Dispensing ▪ Cost performance ▪ Safety
Lack of life cycle environmental impact to all options (P, F, O) ♦♦♦♦♦	Design criteria (P, F, O) ♦♦♦♦ ▪ Materials ▪ Multi-gas usage ▪ Ability to engineer refueling facility to be self-serve ▪ Compatibility	Liquefaction is energy intensive (O) ♦♦ ▪ Greenhouse gases	Community acceptance (P, F, O) ♦♦♦ ▪ Local interests vs. state/national	Cost of H2 technologies higher than current technologies (P, F, O) ♦♦♦♦♦♦♦	Match between demand and production (P, F, O) ♦♦♦
Proprietary aspects (P, F, O) ♦ ▪ Materials data not published	Firm understanding of required purity (P, F, O) ♦♦ ▪ Fuel cells require pure H2, current fuels use mercaptans	Environmental concerns with fossil carbon-based feedstock (P, F, O)	Conflicting regulatory jurisdictions (P, F, O) ♦♦	Risk mitigation (P, F, O) ♦♦♦♦♦ ▪ Investment financial assurance	What are the final delivery points (P) ♦
	CNG not typically at service station (P, F)		Lack of experience and knowledge for operation and maintenance of H_2 technologies (F) ♦♦	Access to affordable capital (P) ♦♦♦	Defined value for carbon (P, F, O) ♦
	What is the key H2 application (P, F, O) ▪ Design requirements		Political resistance to mandates (P, F, O) ♦	Liquid H_2 (F, O) ♦♦ ▪ Cost to liquefy ▪ Transport/storage cost	Lack of knowledge for multi-gas pipelines (P) ♦ ▪ Market/cost?
			Codes/permits (O) ♦ ▪ Access to roads ▪ Safety perception ▪ H_2 venting during transportation	Current weight and capacity of tube trailers (O) ▪ Compressed hydrogen has low energy density ▪ Poor economics for transport over long distance	Storage for local distribution (bulk) (P, F, O)
			Right of way (P) ♦		
			Lack of national management structure (P) ♦		

HYDROGEN DELIVERY NEEDS

(♦ = Number of Votes)

Pertains to (P = pipelines, F = fueling stations, O= other, e.g., barge, rail, truck)

R&D	DEMONSTRATIONS	ANALYSIS	POLICY	CODES & STANDARDS	OUTREACH
Tech validation to address R&D (F) ♦♦♦ ▪ High pressure breakaway ▪ Sensors ▪ Fueling protocol ▪ Robotic refueling ▪ Compressors ▪ Onsite production ▪ Establish public/private partnerships on refueling system/components	Need government sponsored projects in H_2 infrastructure components, e.g., more efficient/economical compressors (P, F, O) ♦♦♦♦♦♦♦♦♦♦♦♦♦ ▪ Include integration of components ▪ Government pilot testing of refueling (similar to CNG)	Environmental- establish consensus on total costs of fuel alternatives (F, O) ♦♦♦♦♦♦♦♦♦	Improve financial incentives (P, F, O) ♦♦♦♦♦♦♦♦♦ ▪ Tax, R&D, demos, govt. as a customer	Support codes and standards development ♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦ ▪ Harmonize codes and standards ▪ Technical expertise ▪ Data access ▪ Test and evaluation ▪ Assure cost effective standards ▪ Installation standards ▪ Assure system compatibility	Public outreach materials (F) ♦♦♦♦ ▪ Branding/marketing ▪ Education ▪ Novel benefits
Study of setback requirements (verification of siting request) (F) ♦♦ ▪ Liquid, gaseous, on-site production, on-site storage	Develop demo roll-out plan (start with several states) to establish delivery (P, O) ♦♦♦♦♦♦♦	Transition strategy- quantify the vision (P, F, O) ♦♦♦♦♦♦♦♦ ▪ Need milestones (e.g., economic, performance, efficiency)	Manage the transition in an integrated way at federal, state and local levels (P, F, O) ♦♦	Establish national hydrogen building code (P, F, O)	Better access to existing info (P, F, O) ♦♦♦
R&D on filter for hydrogen delivery to fuel cell (P, F, O) ♦♦	Prototype wind-hydrogen pipeline to cities (P) ♦♦	Develop options that address all potential delivery points (P, F, O) ♦♦♦♦♦♦♦	Guarantee demand through contractual arrangements with OEMs (P, F, O) ♦♦		Societal dialog on need for hydrogen (P, F, O) ♦♦
Develop benign additives(s) for odor, flame visibility (P, F, O) ♦♦	Design, develop hydrogen planned communities (P, F, O) ♦♦	Analyze current infrastructure suitability for future use (P, F, O) ♦♦♦♦♦♦♦	Enact a carbon tax (P, F, O) ♦♦		Publicizing dissipation risks (F) ♦♦
R&D for new pipelines for liquid hydrogen and electricity together (P) ♦♦	Enable existing hydrogen pipeline to support demonstrations similar to California Fuel Cell Partnership (P) ♦	Create a viable, long-term financial model to profitability (P, F, O) ♦♦	Legislation to expand natural gas right-of-way to hydrogen (P) ♦		
Utilize new storage technology as means for hydrogen delivery (O) ♦	Design criteria (P, F, O) ▪ Merge design standards, knowledge, experience of stakeholders and apply to demos	Assess cost of maintaining existing energy infrastructure (P F, O) ♦♦	Federal standard accounting practice to include social, health, and environmental costs (P, F, O) ♦		

R&D	DEMONSTRATIONS	ANALYSIS	POLICY	CODES & STANDARDS	OUTREACH
			(P, F, O) ♦		
Study co-mingling hazards with other fuels (F) ♦	Customer expectations (F) ▪ Need “community outreach” demo (e.g., public transportation, rental cars, etc.)	Systems analysis of each media for different distances and regions (P, F, O) ♦ ♦	Expand/upgrade natural gas supply infrastructure (P, F, O)		
Need more efficient and economical transportation containers (F, O) ♦		Need stakes in the ground about what the technology is (P, F, O) ♦ ▪ Technical milestones so that fuel delivery and conversion technologies progress together			
Develop and install intelligent sensor system for leaks (P, F, O)		Design hydrogen transmission and distribution system (P, F, O) ♦ ▪ National level			
		Probabilistic risk assessment of systems (P, F, O)			
		Assess the potential impact of existing infrastructure stranded assets (P, F, O)			
		Realistic analysis of demand and production (P, F, O)			
		Conduct geographic information systems analysis for pipeline planning (P)			
		Complete design evaluation of existing pipelines (P)			

Hydrogen Delivery Top Needs

(♦ = Number of Votes) Pertains to P = pipelines, F = fueling stations, O= other, e.g., barge, rail, truck
I = Industry, G = Government, N = National labs, U = Universities, A = Association
(Capital letters: lead, Lower case letters: contributors)

Need	Role	Expected to Occur By
Analyze current infrastructure suitability for future use (P, F, O) ♦♦♦♦♦♦♦	I/G	Prior to 2005
Environmental- establish consensus on total costs of fuel alternatives (F, O) ♦♦♦♦♦♦♦♦♦	G, n, u	2005
Better access to existing info (P, F, O) ♦♦♦	G, I, u, n	2005
Transition strategy- quantify the vision, need milestones (e.g., economic, performance, efficiency) (P, F, O) ♦♦♦♦♦♦♦♦	I/G, n, u	2010
Improve financial incentives (P, F, O) ♦♦♦♦♦♦♦♦♦ Tax, R&D, demos, govt. as a customer	G	2010
Tech validation to address R&D (F) ♦♦♦ ▪ High pressure breakaway, sensors, fueling protocol, robotic refueling, compressors, onsite production, establish public/private partnerships on refueling system/components	I, n	2010
Public outreach materials (F) ♦♦♦♦ ▪ Branding/marketing, education, novel benefits	I (A), g, u, n	2010
Support codes and standards development ♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦ ▪ Harmonize codes and standards, technical expertise, data access, test and evaluation, assure cost effective standards, installation standards, assure system compatibility	I (A), g	2010
Develop options that address all potential delivery points (P, F, O) ♦♦♦♦♦♦♦	I	2020
Need government sponsored projects in the infrastructure components, e.g., more efficient/economical compressors (P, F, O) ♦♦♦♦♦♦♦♦♦♦♦♦♦ ▪ Develop demo roll-out plan (start with several states) to establish delivery (P, O) ♦♦♦♦♦♦♦ ▪ Include integration of components, government pilot testing of refueling (similar to CNG)	G/I	2005 Develop demo roll-out plan 2010 Design feasibility 2030 Commercialization

HYDROGEN DELIVERY NEXT STEPS

(♦ = Number of Votes)
P = pipelines, F = fueling stations, O= other
I = Industry, G = Government, N = National labs, U = Universities

TOP VOTE-GETTING NEEDS	NEED DESCRIPTION	KEY MILESTONES AND DATES	PRIMARY FUNDING ENTITIES	NEXT STEPS
Support codes and standards development ♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦ • Harmonize codes and standards, technical expertise, data access, test and evaluation, installation standards, assure costeffective standards, assure system compatibility	A uniform set of building codes and equipment standards that can be adopted by all jurisdictions for delivery systems	• ICE code hearing- attendance, vote to adopt (April 2002) • NGVC standards development (May 2003) • NFQA hydrogen code development (May 2003) • ISO/SAE code development (drafts)- tanks, connectors, refueling stations (June 2004)	• Government agencies- DOE, DOT, Commerce • Industry- UL certification, National Evaluation Service- product testing	• Issue cooperative agreement to NGVC for standards • Organization meeting at WHEC on harmonizing international activities on codes and standards • Produce codes and standards roadmap- entities, mechanisms for collaboration, information clearinghouse
• Need govt. sponsored projects in hydrogen infrastructure components, e.g., more efficient/economical compressors- include integration of components, govt. pilot testing of refueling (similar to CNG) ♦♦♦♦♦♦♦♦♦♦♦♦♦ • Develop demo roll-out plan (start with several states) to establish delivery ♦♦♦♦♦♦♦	Enhance infrastructure development through demonstrations that showcase and prove out different technologies and components	• Gather key stakeholders from gov/industry to develop demo plan (Dec. 2002) • Gap analysis on technologies to demonstrate (June 2003) • Develop action plans (Dec 2003) • Enact plans and funding (ongoing) • Lessons learned and technology feedback (ongoing) • Build on lessons learned, improve and expand demos (2020)	• Federal government, • State government • Industry	Neil Rossmeissl to set up government/industry meeting on delivery demo plan
Establish consensus on total costs of fuel alternatives ♦♦♦♦♦♦♦♦♦	Need to establish consensus data sets and modeling techniques that will enable the most up-to-date analyses of the total costs (direct and external) of candidate fuels.	• Enumerate fuels (2002) • Identify direct costs and who pays (2002) • Identify indirect/external costs and who pays (2002) • Assemble credible group and develop model (2003) • Industry and government review (2004) • Use outreach program to sell results (2005)	Government	• Identify primary leadership-DOE Steve Chalk • Name interagency and industry work group (3Q, 2002) • Convene working group (4Q, 2002)
Improve financial incentives ♦♦♦♦♦♦♦♦♦ • Tax, RYD, demos, govt. as a customer	Improve financial incentives for delivering hydrogen to markets. This can include tax incentives, federal, state, and local incentives for industry to invest in R&D activities and demonstrations	• Tax credits (2002-2010) • Govt. purchase fleets (2005) • CRADAs for R&D (2002-ongoing) • RFPs for demos (2002-ongoing)	• Federal govt. funding • State tax relief	• Federal govt. issue CRADAs and RFPs • Federal govt. establish fleet vehicle programs in conjunction with OEMs and fuel suppliers • Industry continue to advocate tax credits

Top Vote-Getting Needs	Need Description	Key Milestones and Dates	Primary Funding Entities	Next Steps
	• Govt. funding and tax credits/incentives- federal, state, and local incentives, including R&D • Govt. initiate program to purchase hydrogen technologies and implement delivery • Implement govt. hydrogen fleet vehicle program to include refueling • Govt. issue RFPs on demos for various hydrogen delivery methods (CRADAs, IP concessions, licensing)			• Federal govt. implement tax credits
Transition strategy ♦♦♦♦♦♦♦♦ • Quantify the vision • Need milestones (e.g., economic, performance, efficiency)	Gaining consensus between industry, government, academia on roadmap for transition to hydrogen economy (Delivery of hydrogen)- this should include R&D needs such as identified in this workshop	• DOE roadmap workshop (2002) • Circulate draft widely (2002) • Consider existing milestone data (e.g., economic, performance, efficiency) such as NHA Hydrogen Commercialization Plan, NHA Implementation Plan, HTAP reports, multiyear hydrogen R&D plan, etc. synthesized- prior to finalizing roadmap	• Federal govt. (DOE) hosts workshop(s) • Industry through participation, association consensus, input • Federal govt. (DOE) funds facilitators	• Collect and synthesize hydrogen roadmaps and plans for quantifying the vision (DOE, NHA, academia, others) • Circulate draft roadmap/master plan • Collect and incorporate comments • Publish final report • Education and outreach on vision
Develop options that address all potential delivery points ♦♦♦♦♦♦♦	Identify the option that will supply hydrogen to multiple end users- refueling (comm./retail), industrial parks, retail industry, homes, office buildings	• Team and budget (2003) • Inventory current options and upstream segments (2004) • Gap analysis and requirements (2004) • Functional analysis of delivery needs (2004) • Monitor technology advancement (2004-2020)	• Industry	• Assemble core group of government and industry • Develop information sharing forum/mechanism
Analyze current infrastructure suitability for future use ♦♦♦♦♦♦♦	Better understand existing delivery systems, capacities, potential adaptability to support H_2- H_2 pipelines, NG pipelines (trans/service), refineries, product terminals/ pipelines, logistics, LNG, LH_2 plants, GH2 system, gasoline refuel	• Form team and budget (2002) • System inventory (2002) • Analyze systems- forecast market, costs, feasibility, opportunities (2003) • Report out (2003)	• DOE • Industry in-kind	DOE and industry form team

TOP VOTE-GETTING NEEDS	NEED DESCRIPTION	KEY MILESTONES AND DATES	PRIMARY FUNDING ENTITIES	NEXT STEPS
Public outreach materials ♦♦♦♦ • Branding/marketing, education, novel benefits	Persuade the public that hydrogen is safe to transport as well as convenient and environmentally friendly	• Develop education program for hydrogen targeted for different sectors of population (2003) • Roll out education program (2004)	• Industry • Government	Assign task to outreach group
Tech validation to address R&D ♦♦♦ • High pressure breakaway, sensors, fueling protocol, robotic refueling, compressors, on-site production, establish public/private partnerships on refueling system/components	Testing and validation of components and subsystems used in providing hydrogen to the consumer with evidence of safe operation satisfactory to permitting authorities	• Establish an organization including insurance, government, national labs, and industry to perform testing and certification (end of 2003) • Identify components requiring validation and develop testing protocols (end of 2004) • Conduct testing and validation (ongoing)	• Government • Industry • Insurance providers	Organize testing and validation workshop including all key players (Nov 2002)
Better access to existing info ♦♦♦	Better access to non proprietary information relating to the delivery of hydrogen to avoid duplication of efforts and get a full understanding of what has already been done and currently ongoing	• ID appropriate DOE entity (Oct 2002) • Survey available information from government, industry and associations (June 2003) • Build database (Sept 2003) • Enhance website (Mar 2004) • Routine updates (Annual) • Engage EIA (2003)	• Government	Steve Chalk to build intra agency team

SECTION 4

HYDROGEN STORAGE BREAKOUT SESSION

- **Barriers:** What are the scientific, environmental, engineering, market, institutional, education, and economic barriers for general, physical, and non-physical storage technologies that interfere most with achieving the vision?

- **Needs:** What are the most important needs for storage devices, including codes and standards, crosscutting, education, process, materials, technologies, financing, and others to address the barriers?

- **Next steps:** What are the top priority needs, key milestones, primary funding entities, and primary performing entities for the next steps?

Participants:

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FACILITATOR: Jennifer Miller, Energetics, Inc. (assisted by Jamie McDonald)

Hydrogen Storage Barriers

(♦=Vote for top priority)

Storage Type	Scientific	Environmental	Engineering	Market	Institutional	Education	Economic
General	▪ Development of high capacity lightweight, low temperature, fast kinetics hydrides for transportation (1. Technological barrier, 2. Cost…) ♦ ▪ Energy densities sufficient to gain market acceptance ♦♦♦♦♦♦♦♦ ▪ Lack of complete understanding of metallurgical issues associated with H2 systems. How to prevent H2 embrittlement, etc. ♦♦♦ ▪ Reliability, durability of materials used to handle H2 – Static/dynamic ♦♦♦♦♦ ▪ Lack of interdisciplinary discussion ♦	▪ "End-of-life" disposal/ recycling ♦♦♦	▪ Technology barrier (re: volume, weight, safety, cost) ♦♦♦ ▪ Moving performance targets for mobile and stationary applications ♦ ▪ Meeting all storage requirements simultaneously ♦ ▪ Lack of hybrid storage concepts for various applications ♦ ▪ Lack of integrated vehicle health monitoring for H2 systems ♦ ▪ Compatible components to be developed	▪ Lack of market pull ▪ Limited or no manufacturing infrastructure ▪ Need to meet consumer expectations for safety, range, affordability, "greenness" ♦♦ ▪ Consumer acceptance of the unknown (replacement technology / safety perception ♦ ▪ Lack of agony neutral solutions for consumer (transparency) ♦♦♦♦♦♦♦ ▪ Customers must "get" more from energy storage if they must "pay" more for it ▪ Consumer will not electively pay (much of a) premium for green ♦ ▪ Overly restrictive requirements (eliminates options and diverts resources) ♦ ▪ Difficulty of replacing established	▪ Insufficient funding and support, and requiring cost-sharing ♦♦♦♦♦♦♦♦♦ ♦♦♦♦♦ ▪ Inconsistent or non-existent codes and standards permitting ♦♦♦♦♦♦♦♦♦ ♦♦♦ ▪ Lack of collaboration and exchange of information ▪ lack of the number of researchers – goal not well known ▪ Lack of coordination between government labs & agencies	▪ Lack of safety demo's and acceptance ▪ Lack of education about H2 safety ♦♦♦♦♦♦♦ ▪ Lack of international outlook (communication) ♦ ▪ Expectations/mindset of the American public	▪ Cost reduction in the absence of high volume demand ♦♦♦♦♦♦♦ ▪ Lack of internalizing externalities (true cost of petroleum) ♦ ▪ How many "H2 storage materials" will the economy support? If better materials come along will they be able to economically drop in? ▪ Wise comparison and realistic assumption of cost ▪ Lack of production opportunities ♦

STORAGE TYPE	SCIENTIFIC	ENVIRONMENTAL	ENGINEERING	MARKET	INSTITUTIONAL	EDUCATION	ECONOMIC
				technologies ♦ ▪ Lack of industry leadership in setting high standards for H2 safety and performance			
Physical			▪ Lack of more efficient liquefier technology (FOM >0.5) ♦♦ ▪ Lack of "zero loss" cryogenic tanks that are "smart" ▪ Manufacturing process		▪ No DOT standards for type 3 & 4 tanks for bulk transport and stationary applications ▪ Lack of what pressures will be supported by OEM's & infrastructure (350 bar, 700 bar?)	▪ Lack of education about "cryogenic" characteristics of gaseous energy systems	▪ Cost reduction in composite materials ♦ ▪ Need for lower cost liquefier technology (1. base load, 2. internal, 3. distributed scales) ♦
Non Physical	▪ Lifetime of existing metal hydride materials ♦♦ ▪ Fast charging of H2 for storage in MH ♦ ▪ Lack of storage media with high density, reversible, low temperature H2 and CH4 ♦♦♦♦♦♦♦♦♦ ▪ Inadequate volumetric density in nanotubes ▪ NaAlH4 viable charge/discharge T&P's for portable applications		▪ safety aspects of "storage material plus H2"		▪ No definition of "fast-charging" ▪ Standards for storage of H2 in MH ♦♦♦		▪ Raw material supply/demand (carbon fiber) ♦

HYDROGEN STORAGE NEEDS

(♦=Vote for top priority)

(N = near-term < 2010, M = mid-term 2010 < 2020, L = long-term > 2020)

CODES & STANDARDS	CROSSCUTTING	EDUCATION	PROCESS	MATERIALS	TECHNOLOGIES	FINANCING	OTHER
▪ Alignment of government and other agencies to develop codes and standards ♦♦♦♦♦♦♦♦♦♦ (N) - Set up consortium to demonstrate storage technologies ▪ Develop appropriate codes and standards that will allow for new technologies to grow ♦ ▪ Need to look at process to develop codes and standards ♦	▪ Hydrogen permeation and detection (sensors) ▪ Require "wellhead-to-wheels" energy efficiency analysis for all storage technologies ♦♦♦♦ (N) - Thermo-dynamic limitations	▪ A k-12 and beyond program needs to be developed on H2 storage (gaseous, cyro, and solid state) ▪ Education and outreach program for localities	▪ Processes for developing tanks for mass production ♦♦♦♦♦♦ (N) ▪ Research support for cost reductions in production process of H2 fuel from chemical hydrides ♦ (N)	▪ Integrated and accessible research network incorporating all government agencies providing funding ▪ Coordinated national program to develop alanates (M) , carbon storage (L), metal hydrides (N), and chemical (M) ♦♦♦♦♦♦♦♦♦ ♦ ▪ Stability of hydrides under cyclic loading (long term studies) ♦♦♦ (M) - Mechanism study (alanates, C structure) ▪ Improved fiber and resin performance ♦♦♦♦♦ (N) - lower cost storage technologies	▪ Design for "customer acceptance" technology assessment for H2-fuels (especially storage) ♦♦ (N) ▪ Need for storage technologies for heavy duty vehicles ♦♦ (M) ▪ R&D needs to focus on solid state material systems deign and optimization (heat management, etc) ♦♦♦♦ (M) ▪ Integrated systems (storage with metering, etc) ♦♦♦ (N & M) - Heat integration on-board MH system (reversible) ▪ Zero-loss tank (cyro storage) ▪ Health monitoring technology (cycle counting, strain monitoring) ♦♦ (N)	▪ Each government agencies needs to have a H2 funding program ♦♦♦♦♦ ▪ Increase in funding ♦♦♦♦♦♦ ▪ H2 cross-cutting program ▪ More cohesive national presence among all interest parties ♦ ▪ Expand range of storage technologies supported ♦♦♦♦♦♦♦♦ ♦♦ (L) ▪ Encourage industry funding (oil companies) ♦ ▪ An out of the box call for proposals needs to be offered beyond exploratory ♦♦♦♦♦♦ (N)	▪ Large demos to expedite codes and standards ♦♦♦ (L) - large scale for different storage technologies - raise visibility re (safety, codes & standards) ▪ Streamline implementation of H2 (mobile) technology ▪ Kinetics of hydrogen uptake and discharge ♦

CODES & STANDARDS	CROSSCUTTING	EDUCATION	PROCESS	MATERIALS	TECHNOLOGIES	FINANCING	OTHER
				▪ Novel/new materials (clays, glass spheres, others) ♦ ♦ ♦ ♦ (L) ▪ Hydrogen embrittlement, stress corrosion cracking, permeation ♦ (continuous) ▪ Program to develop high risk technologies ♦ ♦ ♦ (N)			

Hydrogen Storage Next Steps

Top Priority Needs	Brief Description of the Need	Key Milestones and Dates	Primary Funding Entities	Primary Performing Entities	Next Steps
Large scale demos for storage technologies	▪ Demonstrate performance ▪ Public acceptance ▪ Codes & standards ▪ Mobile ▪ Stationary	▪ CG, CH2, Metal hydrides - ongoing -Performance -Public acceptance -Codes & standards ▪ Alanates – 2007 ▪ Carbon, other - 2010	▪ Cost shared between government and industry	▪ Industry ▪ National labs	▪ Demonstrate new technologies as developed
Develop improved materials for containment	▪ Lower cost ▪ Higher performance (fibers & resins, etc) tanks ▪ Reversible & irreversible hydrides, carbon, etc ▪ Chemical	▪ viable storage by 2010 ▪ visible technology demonstrations by 2005 ▪ application specific with other hydrogen technologies	▪ Government and industrial base	▪ Technology: Government, academic, and industrial partners ▪ Market: Industry – industry partnership	▪ Continued optimization of non traditional materials (composites, high risk, unknown)
Alignment of government and other agencies to develop codes and standards	▪ Alignment of C&S agencies needed to complete in time for need	▪ Establish lead person in government - 2003 ▪ Establish coordinated U.S. effort - 2005	▪ DOT ▪ DOE ▪ Industry	▪ DOT ▪ National Laboratories ▪ Industry (SAE, CGA)	
Materials performance under unique or extreme conditions	▪ Fully understand effects of extreme conditions on new containment systems to ensure safety	▪ Now and ongoing effort ▪ Establish database <2010 ▪ Define test protocol <2010 ▪ Test new materials – on going	▪ Government agencies (DOT, DOE)	▪ Established by: national labs and universities ▪ Ongoing validation by independent testing organizations	▪ Establish database on existing materials ▪ Define performance and test criteria
Process for developing mass production H2 storage	▪ Need for process with interim steps to go from lab scale to full mass production ▪ Transition from R&D to high-speed, high volume manufacturing	▪ Compressed - <2010 -System development progress -Inspection techniques ▪ Metal < 2010 ▪ Chemical <2020 -Market pull to drive production efficiency	▪ Industry ▪ DOD ▪ DOE ▪ Cost shard effort between government and industry partnership	▪ Industry ▪ Universities ▪ National labs	▪ Define actual programs ▪ Solicit funding ▪ Consider government incentives to create markets ▪ Broad area announcement to industry, national labs, and universities
Develop novel/new material	▪ Need better performing, lower cost storage	▪ Demonstrate new materials – 2010 ▪ Establish program,	▪ Government ▪ Some industry (in kind, tax credit)	▪ National labs ▪ Universities ▪ Industry	▪ Call for proposals

TOP PRIORITY NEEDS	BRIEF DESCRIPTION OF THE NEED	KEY MILESTONES AND DATES	PRIMARY FUNDING ENTITIES	PRIMARY PERFORMING ENTITIES	NEXT STEPS
		make awards – 2004 ▪ Identify new candidate – 2007			
Program for high risk technologies	▪ Freedom to pursue non-obvious technology solutions independent of traditional performance metrics	▪ Specific accessible funding routes in place by 2004 ▪ Develop high risk technology roadmap & funding profile ASAP (2003)	▪ Government	▪ Government labs ▪ Academia ▪ Industry	▪ Establish a steering committee to develop long-term technology roadmap and funding profile
Achieve a funding level commensurate with importance of storage	▪ Lack of funding to investigate all material possibilities (development and discovery)	▪ Rapid jump in near term ▪ >$100M by 2005 (minimum)	▪ DOE ▪ DOT ▪ US Armed services ▪ Industry (proprietary)	▪ Near term – Gov approximately 80% and decrease level of involvement as time progresses ▪ Near term – Industry approximately 20% and increases as time progresses ▪ Unsure as to whether energy companies should play a role	▪ Maintain a reasonable level that is commensurate with demands and needs over time
Have a coordinated national program to develop H2 storage materials	▪ Need for funded national program for advanced materials research to improve performance and reduce cost ▪ Alanates ▪ Carbon structures ▪ Metal hydrides ▪ Chemical	▪ ID areas of research - <2010 ▪ Set up funding - <2010 ▪ Manage program -Existing technologies 2010<2020 -New materials >2020	▪ Government ▪ Industry	▪ Industry ▪ Universities ▪ National labs	▪ ID level of funding needed ▪ Secure funding

SECTION 5

HYDROGEN ENERGY CONVERSION BREAKOUT SESSION

- **Barriers:** What are the scientific, engineering, market, financial, and institutional barriers that interfere most with achieving the vision?
- **Needs:** What are the most important needs for fuel cells and combustion devices, including research, technology development, demonstration, codes and standards, analysis, institution building, market development, legislation, and education and training?
- **Paths forward:** What are the top priority needs including, their scopes, key milestones, next steps, and partnerships?

Participants:

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FACILITATOR: Rich Scheer, Energetics, Inc. (assisted by Tara Nielson)

Hydrogen Energy Conversion Barriers

(♦=Vote for top priority)

Scientific	**Engineering**	**Market** *(Both Fuel Cells and Combustion)*	**Financial**	**Institutional** *(Both Fuel Cells and Combustion)*
Fuel Cells • Lack of fundamental understanding prevents "marriage" of electrochemistry with materials science ♦♦♦♦♦♦♦♦♦ • Insufficient focus and coordination of current R&D programs ♦♦♦ • Unsolved sealing, joining, and interconnect materials issues in SOFC • Lack of fundamental understanding prevents progress in making fuel cells more durable and affordable **Combustion** • Lack of understanding about safety implications of H_2 combustion properties ♦♦ • Lack of low cost materials in combustion systems for using H_2 ♦	**Fuel Cells** • High costs of materials and manufacturing for all fuel cell types ♦♦♦♦♦♦♦♦♦♦♦ – Membranes and catalysts for PEMs • Unproven durability and reliability of performance ♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦ – Lack of demonstrated service life and performance • Start-up time less than needed (depends on fuel cell type and application) ♦♦♦ • Safety issues have not been adequately addressed (for both fuel and fuel cell) ♦ • Unsolved corrosion issues in MCFC • Questions about performance under differing environmental conditions and geographic locations **Combustion** • Lack of proven engine and turbine performance using H_2 ♦♦♦♦♦♦♦♦ – Emissions – Efficiency – Safety – Vehicle range, power versus load, use in heavy duty vehicles • Lack of understanding about flame requirements and impacts on engine designs ♦♦♦♦ – Flame management in turbines • Combined cycle combustion turbines using natural gas are relatively clean and very efficient, why use H_2?	• Market (Both Fuel Cells and Combustion) • No market pull for clean power ♦♦♦♦♦♦♦♦♦ • Oil is cheap (public has short memory) ♦♦♦♦♦ • No value proposition for using H_2 rather than fossil fuels ♦♦♦♦♦ • No clear business model for profitable widespread distributed energy market ♦♦♦♦ • No H_2 fueling infrastructure♦ • Public has no idea of H_2 advantages ♦	**Fuel Cells** • Overly optimistic projections of fuel cell business growth • Lack of incentives to address high capital costs ♦ **Combustion** • Turbines will outperform recips for locomotive/marine applications but will be much more expensive **Both Fuel Cells and Combustion** • Financial markets have no confidence in the predictability/stability of this sector ♦♦♦♦♦♦♦ – Lack of commercial drivers • Large risks of being overcome by competing technologies ♦♦♦ • No source of "patient" capital ♦ • No clear early market leader for development or adoption	• Lack of coordinated development of technical requirements and conformity assessment methods to deliver necessary confidence in safety and reliability ♦♦♦♦♦♦♦♦ – Lack of product safety standards – Lack of building and utility codes • Lack of clear national policies for H_2 and conversion devices ♦♦♦♦♦♦♦ – Lack of sufficient and sustained R&D funding – No value for carbon reduction/sequestratio n • Lack of national support for enforcement of higher efficiency/cleaner air regulations (e.g. CAFÉ) ♦ – No legislation that compels action – Not enough tax credits

HYDROGEN ENERGY CONVERSION NEEDS

(♦=Vote for top priority)
[I=Industry; G=Government; U=Universities; L=National labs; SD=Standards developing organizations]
[N*= by 2005; N= by 2010; M= by 2020;L= by 2030]

FUNDAMENTAL RESEARCH FOR FUEL CELLS	TECHNOLOGY DEVELOPMENT FOR FUEL CELLS	FUNDAMENTAL RESEARCH FOR COMBUSTION	TECHNOLOGY DEVELOPMENT FOR COMBUSTION	DEMONSTRATIONS OF FUEL CELLS AND COMBUSTION DEVICES	CODES AND STANDARDS FOR BOTH FUEL CELLS AND COMBUSTION
• Electrochemistry ♦♦♦ I&G; N-M-L • Interface ♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦ I&G; N-M-L – Ceramics – Characterization methods – Degradation mechanisms – High temperature PEMs – Low temperature SOFCs • Materials Science ♦♦♦♦ I&G; N-M-L – Stack materials – Oxygen cathodes – Membranes	• Enhanced manufacturing capabilities ♦♦♦♦♦ I; N-M-L – Large volumes – Better consistency and quality control – Better fabrication techniques • Expanded consideration of all types of fuel cells ♦♦♦♦ G; N • Component cost reductions through a more reliable supply chain ♦♦♦ I; N* – E.g., Lower cost power electronics	• Higher efficiency H_2 engines and turbines ♦♦♦♦♦♦♦♦♦♦ I&G;N-M-L – Higher temperature materials – Better sensors and instrumentation – H_2-fossil fuel blending • Better techniques for H_2 combustion management and control ♦♦ I&G;N-M-L	• Engine designs and after treatment controls for low NO_x ♦♦♦♦♦♦ I; N – Engines – SCR for turbines • In-situ use of H_2 as a NOx reducing agent ♦♦ I; N • Integrated H_2 storage release and engine/turbine controls ♦♦♦ I; N • Recip engine designs and controls for H_2 blends ♦♦ I; N* • Turbine designs and controls for H_2 blends ♦ I; N • H_2 catalytic combustors and controls for large turbines ♦ I; N • Better H_2 sensors for leak controls ♦ I; N* • Lower cost components, e.g., fuel injectors, sensors	• Expand existing demonstrations of fuel cells, IC engines, and turbines in both stationary, mobile, and portable applications ♦♦♦♦♦♦♦♦♦♦♦♦♦♦ G; N* – Power parks and fueling stations – Test for reliability of advanced materials – Test for durability of performance • Validate product attributes by in-service field testing to establish durability, cost effectiveness, and life cycle efficiency ♦ I; N	• Product safety standards for mobile and stationary applications ♦♦♦♦♦♦♦♦ SD;N • Amend/extend existing building, vehicle, utility codes to enable day-to-day business ♦♦♦ SD;N – Utility interconnection – Power quality – Plumbing and connections • Safety standards for H_2 fuels and fuel quality ♦♦♦ SD;N

HYDROGEN ENERGY CONVERSION NEEDS *(CONTINUED)*

(♦=Vote for top priority)
[I=Industry; G=Government; U=Universities; L=National labs; SD=Standards developing organizations]
[N*= by 2005; N= by 2010; M= by 2020;L= by 2030]

ANALYSIS FOR BOTH FUEL CELLS AND COMBUSTION	INSTITUTION BUILDING FOR BOTH FUEL CELLS AND COMBUSTION	MARKET DEVELOPMENT FOR FUEL CELLS AND COMBUSTION	LEGISLATION	EDUCATION AND TRAINING
• Market analysis with product requirements and timing ♦♦♦♦ I; N • Catalogue (electronic database) of existing research findings ♦♦♦♦ G; N* • Software tools to simulate vehicle collisions for H_2 fuels ♦♦ I; N • Benefits/impacts of reduced carbon emissions on the environment ♦ G; N* • “Killer applications” for fuel cells • Architecture of H_2 fuel distribution system • Accelerated testing	• Enhance, expand, and integrate fuel cell and H2 combustion research and form “National Center” for pre-competitive efforts ♦♦♦♦ I&G; N* – Inform industry of national lab resources • Public-private partnerships for bridging technologies • Industry collation building to promote H_2 in IC engines for vehicles •	• Understand and communicate value propositions ♦♦♦♦ I; N* • Attract more investment to finance small fuel cell businesses ♦♦♦♦ I; N* • Guaranteed market will justify H_2 engine development • Large markets will drive cost reductions	• EPA vehicle emissions regulation flexibility for H_2 fueled engines ♦ G; N* • More financial incentives for H_2 conversion technologies • Government mandates to facilitate market development • Net metering	• Installers and technicians • Emergency responders

HYDROGEN ENERGY CONVERSION PATHS FORWARD

TOP PRIORITY NEED	SCOPE	KEY MILESTONES	NEXT STEPS	PARTNERS
Fuel Cell Research	• Broad materials science • Improved reliability • Improved durability • Lower Cost	• Catalysts with 50% better performance and 50% cost reduction • 120-120 degree C PEM • 500 degree C ionic conductors (400 degree C in ten years)	• Evaluate on-going research • Re-focus on roadmap priorities	• Industry-government partnerships • Cost-shared R&D • With universities and national labs
Fuel Cell Technology Development	• Stacks • Components • Systems • Manufacturing	• Evaluate existing program targets • Modify as needed • Set priorities for cost reduction strategies		
Fuel Cell Demonstrations	• Customer involvement • Evaluation and dissemination • Products not technologies • Fleets not individuals	• Commercial sale of products • Natural outflow of successful technology development • Strategy to collect results and disseminate • Will happen, challenge is to make valuable		
Combustion Research	• Covers all devices and applications • Improve power density • Optimize "knock management • Integrate on-board storage with fuel injection • HCCI research • Turbine systems fuel injection mixing, dilution, and controls • Materials • Modeling and analysis of vehicle collisions	• Systems analysis of H2 fuel cycle for all devices and applications	-Expand DOE combustion research activities	Industry-government partnerships -Cost-shared R&D -With universities and national labs
Combustion Technology Development				
Combustion Demonstrations				
Product Safety Standards	• All fuel cell types • Turbines • IC engines • Stationary and mobile	• Select standards developers by 2003 • Propose standards by 20034 • Begin development by 2003 • Publish 2005		UL, IEEE, CGA, ISO, DOT, CSPC, Trade Associations, AHJs, DoD, DOE
	• H_2 vehicles	• Select standards developers by 2003 • Propose standards by 20034 • Begin development by 2003 • Publish 2005		SAE, DOT, DOE, Insurers, CGA, Auto Associations

TOP PRIORITY NEED	SCOPE	KEY MILESTONES	NEXT STEPS	PARTNERS
Amend Existing Codes and Regs	• FCs, turbines, and engines in buildings • H_2 plumbing and storage	• Select standards developers by 2003 • Propose standards by 20034 • Begin development by 2003 • Publish 2005		• NFPA, ICC, ASME, DOT, DOE, CSA, CSPC, Insurers
	• Utility interconnection	• Existing IEEE process		• IEEE, DOE, FERC, Trade associations
National H2 Energy Conversion Center(s)	• Semitech model • Virtual entity • Pre-competitive R&D • Fuel cells, engines, recips • Stationary and mobile • H_2 fuel blends/mixing	• Evaluate existing R&D entities in 2002 • Develop charter for new integrated organization by 2003 • Establish new organization 2003 • Develop R&D plan 2--3		• Government – DOE, DOD, NASA, DOT, EPA, DOC • Industry – Auto, Energy, Equip Manufacturers • Labs • Universities
Research Compendium &Database	• Public domain documents • Covers all devices and applications • Widespread dissemination	• Develop scope and issue competitive solicitation 2002 • Begin development 2003 • Working product 2005		• DOE and selected contractor

Section 6
Hydrogen Applications Breakout Session

- **Barriers:** What are the barriers that interfere most with achieving the vision?
- **Needs:** What are the most important needs to undertake between now and 2030 to address the barriers and achieve the vision?
- **Top needs and next steps:** What are the top needs, including their key milestones and dates, primary funding entities, and next steps to addressing them?

Participants:

Name	Organization
Frank Balog	Ford Motor Company
Ed Bless	H2 Solutions
Andrew Browning	Methanex, Inc.
David Bruderly	Clean Power Engineering
Ken Cameron	General Motors
Rodney Carlisle	History Associates
Kipp Coddington	Covington and Burling
William Craven	DaimlerChrysler
Erin Cready	Sentech, Inc.
James Daley	U.S. Department of Energy
Jason Francque	Deere & Co.
Michael Gan	Hamilson Sundstrand
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Mark Grist	QuestAir Technologies
Michael Hainsselin	Praxair
Jim Hempstead	
Raphael Herz	Massachusetts Renewable Energy Trust

Participants:

Name	Organization
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Ferris Kawar	ATTIK
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Ben Knight	Honda R&D
Jaimie Levin	Alameda Contra Costa Transit
James Lide	History Associates, Inc.
Maggie Mann	National Renewable Energy Laboratory
Robert Mauro	U.S. TAG ISO TC 197
James Miller	Argonne National Laboratory
Terry Penney	National Renewable Energy Laboratory
Richard Rashilla	Lincoln Composites
Jerry Rogers	GM R&D Center
Michael Romanco	Gas Technology Institute
Andrew Searcy	So. Hydrogen Fuel Cell Research Partnership
Kenneth Stroh	Los Alamos National Laboratory
Bruce Wood	John Deere

Facilitators: Jack Eisenhauer, Keith Jamison, Energetics, Inc. (assisted by Charlie Smith)

BARRIERS - APPLICATIONS (MOBILE) (1 of 2)

✪ = Most Critical Barrier

COMPONENT TECHNOLOGY	SAFETY	CONSUMER AND MARKET ACCEPTANCE	TECHNOLOGY DEVELOPMENT STRATEGY	SUPPORTING INFRASTRUCTURE	COMPETING TECHNOLOGIES, FUELS AND INFRASTRUCTURES	PUBLIC POLICY
▪ Lack of on-board storage technology ✪✪✪✪✪✪ ▪ Demand for hydrogen vehicles is limited by performance/cost ✪✪✪✪ ▪ Lack of on-board reforming technology ✪✪✪ ▪ Materials limitations ✪ - science - applications ▪ Components: - radiators - compressors - storage ▪ Cost and functionality of end-use technology	▪ Perceived safety issues ✪✪✪✪✪ ▪ Developing a safe fueling interface/ procedure ✪✪✪ ▪ Electrical safety issues	▪ Customer perception of cost/benefit ✪✪✪✪✪✪✪✪✪✪✪✪ ▪ Customer acceptance and retraining regarding vehicle range and refueling time ▪ Perceived lack of public acceptance of hydrogen	▪ Lack of national leadership for long-term strategy ✪✪✪✪✪✪✪✪✪✪✪ ▪ Lack of obvious infrastructure pathway ✪✪ ▪ Burden of technology development costs for core and enabling technologies ✪✪ ▪ Planned, incremental technology migration ▪ No coordinated plan ▪ Lack of innovative technology integration	**<u>Fueling</u>** ▪ Chicken vs. egg, infrastructure vs. vehicles ✪✪✪✪✪✪✪✪✪ ▪ Limited hydrogen availability ✪✪✪ - lack of hydrogen fueling infra-structure ▪ Hydrogen production technology must draw upon a diverse energy feedstock, must be impact sensitive **<u>Other</u>** ▪ Parts of the mobile infrastructure ✪✪ - parking garages - service stations ▪ Lack of practical codes and standards ✪✪ ▪ Lack of mechanics training standards	▪ Low-risk, old technologies inhibit development of new, risky technologies ✪✪✪✪✪✪✪✪✪ ▪ Institutional ✪✪✪✪ - stranded cost - regulations ▪ Cost of existing fuels too cheap ✪✪ ▪ Lack of insurance for risk mitigation (safety and economics) ✪ ▪ Alternative choices ✪ - fuel cells - ICE's - turbines - stirling ▪ Sunk costs of existing manufacturing technologies, labor structure sales and service network ▪ Low consumer cost of existing mobile technologies is hard to overcome	▪ Uncertain long-term program and political commitment (> 20 years) ✪✪✪✪✪✪✪✪✪✪✪ ▪ Lack of a sustained financial commitment from the government ✪✪✪✪✪ ▪ Conflicting perceptions of "social good" provided by energy ✪✪✪ ▪ Political partnership over energy resource, energy development choice ✪ ▪ Social benefits not clearly articulated ▪ Uninformed decisionmakers ▪ Economics of carbon-free generation of hydrogen, reliance on hydrocarbon feedstocks ▪ Public perception of problem - available gas - smog

BARRIERS - APPLICATIONS (STATIONARY) (2 of 2)

✪ = Most Critical Barrier

INSTITUTIONAL/REGULATORY	MARKET (MIS)PERCEPTIONS	SCIENTIFIC/ENGINEERING	MARKET DEVELOPMENT	EDUCATIONS
▪ No premium received for "clean fuel" ✪✪✪✪✪✪ - need environmental driver for conversion ▪ Too much policy emphasis on fuel cells, not enough on ICEs ✪✪✪✪✪ ▪ No national, uniform interconnect standards ✪ ▪ Not enough policy emphasis on fuel benefits, public/social costs ✪ ▪ Safety codes and standards not generally known (or available) ✪ ▪ End-users lack of clarity on siting process ▪ Regulatory-hydrogen plants A.Q. permits? ▪ Uncertainty with electric power restructuring/ deregulation ▪ Central power orientation in institutions and policies ▪ Portable, no standard to allow shipping hydrochloride storage containers ▪ If zero net CO_2 is a goal, distributed fossil fuel systems are problematic ▪ Lack of a supportive consortium for innovative industries ▪ Lack of air pollution control integration with industry ▪ Pollution costs are external to fuel cost	▪ Perception of hydrogen safety and accident risks ✪ ▪ Lack of perceived solutions for hydrogen ✪ ▪ Customers may be risk-averse ▪ Traditional energy sources viewed as cheap, available, and acceptable ▪ Customers' perception that there is a limited choice of stationary products ▪ Unrealistic expectations about opportunity for residential-type applications of PEM ⇒ potentially misdirects funding	▪ Portable: Lack of cheap, efficient, long-lived fuel cell ✪✪✪✪✪ ▪ Fuel cell life is inadequate ✪✪✪✪ ▪ Stationary: Cost of hydrogen storage, particularly at locations of low power cost ✪✪✪ ▪ Cost of hydrogen storage (especially for renewable hydrogen) ✪✪✪ ▪ Investment communities have short-term payback horizon ✪✪✪ ▪ Hydrogen systems are too complex ✪✪ ▪ Immature technologies ✪ - fuel cells - reformers - system integration ▪ Systems not optimized for hydrogen ▪ Distributed carbon sequestration with small hydrogen production ▪ Limited features of small-scale reformers ▪ How to convert natural gas pipeline to hydrogen pipeline? ▪ Cost of small-scale reformers ▪ Demand changes ▪ Fuel cell price per kW too high ▪ Cost and storage of renewable energy ▪ Limited incentives for utility industry deployment ▪ From the utility perspective, cost-compared to natural gas - wholesale vs. retail	▪ Lack of support and funding for hydrogen business newcomers ✪✪✪✪✪ ▪ Lack of fuel delivery infrastructure ✪✪✪✪✪ ▪ Little incentive for early adopters ✪✪✪ ▪ Availability of hydrogen, specialty chemical, not a fuel ✪✪✪ ▪ Lack of "killer applications" ✪✪ - length-of-use issue ▪ Need success on mobile side for stationary adoption ✪✪ ▪ Lack of talent in hydrogen-related industries (human capital) ✪ ▪ Lack of coordinated effort for different application areas ▪ Applications are small ▪ Geographic issues with fuel infrastructure - need to join with rest of the distributed generation market ▪ No mass production, no product available for hydrogen turbines (MW scale), and hydrogen ICEs (piston) ▪ Combined heat and power is not a way of operating in the United States ▪ Who will service? - how often? - disruption?	▪ Lack of public education (what is driver?), why go to hydrogen? ✪ ▪ Lack of knowledge among code officials ▪ Need more familiarity with equipments, safety, codes, insurance issues ▪ Limited awareness and understanding of potential efficiency and environmental benefits

Applications Needs to Address the Barriers and Achieve the Vision by 2030

(✪ = Most Critical Barrier)

Time Frame: (N = Now-2010; M = 2010-2020; L = 2020-2030+)

Lead (capital letters) and Supporting (lower-case letters) Roles: (I = Industry; G = Government; U = Universities; NL = National Labs; TA = Technical Associations)

Regulations, Codes, Standards	Demonstrations and Test Beds	Public Policy	Application Technologies	Hydrogen Production	Technology Development and Partnership	Market Conditioning
▪ Standards agreement (N) ✪✪✪✪✪✪✪✪✪ **T, A,G** - intelligent, technically-based - urgent need ▪ Progressive expansion of small-scaled demo programs to build consumer, customer confidence and refine technology ✪✪✪ ▪ International code, make friendly for hydrogen change - International Fuel Gas Code - National Electric Code ✪✪ ▪ Focused approach to achieve "critical mass" in technology rollout and demonstrate pathfinder approach ✪ - don't dilute scarce resources ▪ Government regulation to set requirements and drive technology and market development	▪ Assist development of community-based applications and installations (NM) ✪✪✪✪✪ **GI** - hydrogen industrial/theme park - demos cannot precede public policy standard - PIXAR movie showing hydrogen man overcoming fossils ▪ Assist development of fleet-based applications ✪✪✪✪ - 50,000-vehicle market in one spot using fleet clusters fueled by hydrogen ▪ Practical demonstrations to validate technical development ✪✪✪✪ ▪ Create hydrogen application incubators ✪✪	▪ Government serves as the early adopter customer (N) ✪✪✪✪✪✪✪✪✪✪ ✪✪ **GI** ▪ Public policy ✪✪✪ - concerted education - demonstrations - engaged debate ▪ National announcement by President Bush on a national hydrogen mission ✪✪✪ ▪ Develop consensus middle ground view that nation needs to move away from fossil fuel reliance ✪✪ ▪ Federal and state transition incentives ✪ ▪ Public policy incentives ✪ - tolls (road bridge) - parking - HOV lanes - extrusion zone ▪ Benchmark other (foreign) government policies ✪ ▪ Government policy for price parity with other fuels (gas) ✪ ▪ Hydrogen—the freedom fuel (energy carrier) ✪	▪ On-board storage ✪✪✪✪✪✪✪✪ **I** (applications) **G/NL/U** (gaps and fundamental research) - more concentrated R&D on diverse storage media - reliability, low cost - volume - nano tech (L) - sodium borohydride (M-L) - gas 5/10 (N) - liquid (N) ▪ Very short-term hydrogen end use technology development for market readiness (i.e., ICE, high pressure tank) (N) ✪✪✪✪✪✪ **I** (initiate) **G** (funding) - Use ICEs as enabler to support hydrogen infrastructure ▪ Low-cost stack and systems (NML) ✪✪✪✪✪ **I** (applications) **G** (gaps, funding) - ultra cap/bat - high temperature membrane	▪ Capture intermittent renewable energy to produce hydrogen ✪ ▪ Leverage hydrogen production for multiple uses at central location-airports, fleets, GSEs, backup stationary ✪ ▪ More deployment of current hydrogen waste streams ✪ - system optimization of hydrogen production technologies (i.e., refineries) similar to that done with heat exchanger technology in the 70s and 80s ▪ Near-term hydrogen production, infrastructure utilization (i.e., refineries) ▪ Reduce the cost of hydrogen to give fuel parity with natural gas	▪ Create Federal, state, and local, and private partnership program to demonstrate systems (N) ✪✪✪✪✪✪✪✪✪✪✪ ✪**G, I** ▪ Provide government leadership and financial support for infrastructure development (N) ✪✪✪✪✪✪✪**G** (partnership) **I** - e.g., public/private partnership and joint funding of hydrogen fueling - SEMATECH, NASA ▪ Consortium approach to critical R&D items ✪✪✪ ▪ Credible evaluation programs for technology development and building public and institutional support ✪ - costs (life cycle) - public acceptance - industry acceptance - performance ▪ Draw upon natural gas solutions and experience to benefit hydrogen (understand pathway) ✪✪ ▪ Open sharing of "pre-competitive" R&D ✪	▪ Make local demonstration projects national through news events, town hall meetings, etc. (N) ✪✪✪✪✪✪✪ **G I** ▪ Increased exposure to hydrogen at all levels of education system, dispel the myths ▪ Consumer acceptance ✪✪ - warranty - service - education - demo's ▪ Hydrogen production and fueling that does not look like a mini refinery or chemical plant ▪ Consumer acceptance - systems must be workable - cars must work - incentives, early adopters

APPLICATIONS NEEDS TO ADDRESS THE BARRIERS AND ACHIEVE THE VISION BY 2030

(✪ = Most Critical Barrier)

Time Frame: (N = Now-2010; M = 2010-2020; L = 2020-2030+)

Lead (capital letters) and Supporting (lower-case letters) Roles: (I = Industry; G = Government; U = Universities; NL = National Labs; TA = Technical Associations)

REGULATIONS, CODES, STANDARDS	DEMONSTRATIONS AND TEST BEDS	PUBLIC POLICY	APPLICATION TECHNOLOGIES	HYDROGEN PRODUCTION	TECHNOLOGY DEVELOPMENT AND PARTNERSHIP	MARKET CONDITIONING
	- test bed environment ▪ "Broad Based Deployments" of hydrogen and fuel cell technologies (G) Dykema Gossett, PLLC	carrier) ✪ ▪ Making fleet demonstrations effective: DOT and DOE/DOD, EPA must coordinate programs/activities ▪ Public Policy Steps - bipartisan - demos (Fuel Cell, ICE) - tax incentives - education - branding	- advance comp - H_2 sensor - manufacturable membrane ▪ Reliability and durability of operating systems (N-L) ✪✪✪✪✪ ▪ Fuel infrastructure-chicken/egg ✪✪ - need for small-scale, user-friendly, low-cost fueling device ▪ Redesign auto for early adoption ✪✪ ▪ Alleviate strain on stationary fuel cells by subsidizing distributed PVs and wind ✪ ▪ Increase hydrogen in topping cycle turbines for power generator ✪		competitive" R&D ✪ ▪ Super coordination of hydrogen efforts (international) ▪ Support cost/benefit analysis for CHP and vehicle fuel deployment in residential/small office	

TEN MOST WANTED – APPLICATIONS (1 of 3)

TOP VOTE GETTING IDEAS	BRIEF DESCRIPTION OF THE NEED	KEY MILESTONES AND DATES	PRIMARY FUNDING ENTITIES	NEXT STEPS
Agree on Intelligent, Technically-Based Standards	▪ Consensus among states ▪ Harmonization with international standards ▪ Increase level of attention in United States			▪ Build consortium of agencies (e.g., DOT, EPA, California Air Resources Board [CARB]) to set codes, ’02-’03 precede early applications ▪ Intensive process, feedback from lessons learned and new technologies 2 years later
Create Federal-State-Local-Private Partnership Program to Demonstrate Systems	▪ Government (less risk adverse) regulating change gives industry direction and assurance on where private investment should go ▪ Government is more sensitive to public policy issues and the global impacts and externalities of existing consumer demand	▪ Alternative fuel mandate in 2001 requiring bus fleets in southern California to use fuels other than diesel ▪ CARB ZEV mandate for bus fleets - 2003 demo - 2008 15% of all vehicles ▪ CaFCP bus fleet demonstration begins 2004 ▪ Establish similar Federal mandate	▪ DOE and DOT ▪ Car registration fees ▪ Public and private partnerships ▪ Local and state funding	▪ Federal plan backed up by federal money ▪ Benchmark California
Establish Government as Early Adopter Customer	▪ Implement as many demonstration programs to introduce and evaluate emerging technologies	▪ Federal government needs to mandate hydrogen programs for all government agencies today ▪ Enforce present law (Energy Policy Act of 1992) ▪ Fully funded, well-designed demonstration programs beginning with FY 04	▪ DOE and DOT (T21 reauthorization) are primary funding sources	▪ Substantially fund Hydrogen Futures Act in FY 04 ▪ Fund successful demonstration programs on a sustained basis ▪ Adopt “Freedom Fuel” Action Plan along with Freedom Car Program
Provide Government Leadership and Financial Support for Infrastructure Development	▪ Develop limited number of demonstration sites for infrastructure using California Fuel Cell Partnership model ▪ Private industry financial criteria only supports term projects	Milestones: ▪ Fleet demos (< 100) – immediate ▪ Fleets (5,000+ in United States) – 2008-2012	▪ DOE ▪ DOD ▪ DOT ▪ State and local	
Develop Very Short-Term Hydrogen End-Use Technologies to Stimulate Infrastructure and Market Readiness	▪ Promote and develop near-term products and technologies to stimulate and accelerate the implementation of hydrogen infrastructure ▪ Have regulatory agencies adopt philosophy of encouraging this approach (i.e., in lieu of ZEV mandate	▪ Stationary power generation 500 stationary units ▪ Generate the market by FY 03 and FY 04 with the purchase of fleets that use these technologies	▪ Continued DOE support	• Fuel cell report to Congress • Hydrogen Futures Act • Let’s not wait for the Holy Grail!

TEN MOST WANTED – APPLICATIONS (2 of 3)

TOP VOTE GETTING NEEDS	BRIEF DESCRIPTION OF THE NEED	KEY MILESTONES AND DATES	PRIMARY FUNDING ENTITIES	NEXT STEPS
Research and Develop On-Board H_2 Storage Systems	▪ Duplicate range of equivalent gasoline vehicles ▪ Hi pressure gas - low weight/high strength - permeation standards Requires: ▪ R&D engineering - high pressure - hydrides - nanotechnology ▪ Codes and standards	▪ 6% by weight ▪ Ultimate goal 7-8%	▪ DOE - national laboratories ▪ Industry	▪ Build demo's for 6, 7, 8% systems ▪ Qualify Suggestions: ▪ Study Sematec example for application to hydrogen and fuel cells (Bob Walker)
Develop Low-Cost Stack and Systems	▪ Increase life (reliable/durable) ▪ Reversible ▪ Decreased cost (comparable to ice) Requires: ▪ research/engineering - high volume manufacturing - high temperature membrane - sensors/controls - advanced components (compressors. . .) - catalyst loading - hybrids (ultra cap/battery) - basic material science	▪ Fuel cell report to congress dates	▪ DOE/DOD ▪ Industry ▪ States ▪ DOT	▪ Build demo's (fleets/off-road) ▪ Qualify ▪ Codes, standards
Assist Development of Community-Based Clustered Applications and Installations	▪ Seed the creation of mini hydrogen economies	▪ Issue RFP - FY 03 ▪ Select winners - FY 04 ▪ Commence building - FY 05 ▪ Complete installations by 2010	▪ Federal Grants (DOE) 70% ▪ State/local cost share 20% ▪ Industry cost share 10%	▪ Develop the RFP solicitation

TEN MOST WANTED – APPLICATIONS (2 of 3)

TOP VOTE GETTING NEEDS	BRIEF DESCRIPTION OF THE NEED	KEY MILESTONES AND DATES	PRIMARY FUNDING ENTITIES	NEXT STEPS
Improve Reliability and Durability of Operating Systems	▪ To warranty hydrogen infrastructure and products to the same level as conventional systems	▪ Develop performance-predictive analysis tools ▪ Field trial validation (ongoing)	▪ National labs establish generic models, procedures, and criteria ▪ Industry applies results to products	▪ Establish certification facility at a national lab
Promote/Publicize Local Demonstration Products Nationally through News Events, Town Hall Meetings, etc.	▪ Public image of hydrogen as a fuel is absent ▪ Need to educate public, state and local officials, schools, corporations, government, decision-makers, media, industry organizations	▪ Documentaries (now) ▪ News events ▪ Safety videos ▪ Training ▪ Ride and drive	▪ Joint DOE/Industry ▪ SAE, NHA ▪ API ▪ Other industry associations ▪ State and local government	

SECTION 7

HYDROGEN OUTREACH AND EDUCATION BREAKOUT SESSION

- What are the key hydrogen messages to communicate for education and outreach?
- Who are the target audiences?
- What are the barriers that most interfere with achieving the vision?
- What actions must be taken to address the barriers and achieve the hydrogen vision?
- What are the top priority action plans for education and outreach?

Participants:

NAME	ORGANIZATION
Shannon Baxter	California Air Resources Board
EJ Belliveau	H_2 Solutions
Maria Bellos	Fuel Cells 2000
Christine Messina-Boyer	Millennium Cell
Ken Cameron	General Motors
Bill Clapper	Sunline Transit
Mary-Rose de Valladares	DCH Technology, Inc.
Marshall Gilmore	Florida H2 Business Council
Art Hartstein	U.S. DOE, Fossil Energy
Katie Hoffner	Hydrogen Now!
Peter Holran	Wexler & Walker Public Policy Assoc.
Jonathan Hurwitch	SENTECH, Inc.
Susan Leach	Hydrogen 2000, Inc.
Jennifer Schaeffer	Plug Power Inc.
Greg Schuckman	University of Central Florida/ Florida Solar Energy Center
Jeff Serfass	National Hydrogen Association
Lauren Segal	BP
Charles Veley	US Hydrogen
Greg Vesey	Chevron Texaco
Suzanne Watson	Northeast-Midwest Institute
Steve Zimmer	Daimer Chrysler

FACILITATOR: Jan Brinch, Energetics (assisted by Lauren Giles)

MESSAGES

- Need to "brand" hydrogen
- This is a long-term proposition
- Cleaner, more dependable, secure fuel
- Domestic = independent
- Source of hydrogen gives flexibility/diversity
- "A" hydrogen economy—integrated with other fuels (as opposed to "the" hydrogen economy)
- Hydrogen is another—not the only—energy source
- "Safe"
- Economics, environment, security
- Hydrogen is "cool," culturally "hip"
- "Pop" culture
- Bring down to "the peoples' level"
- Hydrogen is affordable—is it?
- Consumer convenience
- For stationary as well as vehicles
- Cost-effective in rural areas
- Environmental interests of the young
- Predictability
- Know the audience
- Hydrogen age must be inclusive—build on existing efforts
- Hydrogen must be affordable
- Need to tie in climate change and dependency on foreign oil
- Market to global economy
- Hydrogen and fossil fuel industry nexus

TARGET AUDIENCES

- John Q. Public
- K-12 school age children
- College students
- Policy makers (decision makers and legislators)
- State PUCs
- Local and state code officials
- Allied industries—secondary
- Science teachers
- Industry executives
- Professional/trade associations
- Media and press (trade and mainstream)
- Early adopters
- Service station operators and owners
- Transit agencies
- Foundations
- R&D community
- Government agencies
- Vehicle fleet owners/operators
- Regional planning organizations
- Environmental groups
- Multilateral institutions (World Bank, etc.)
- Commercial electric consumers (with high demand)
- FIRE: (Financial—lenders, investors, Insurance, Real Estate industries)

Hydrogen Education and Outreach

WHAT ARE THE BARRIERS THAT MOST INTERFERE WITH ACHIEVING THE VISION?

PUBLIC AWARENESS	EXAMPLE/SUCCESS STORIES	EDUCATION *(Students)*	BUSINESS INVESTMENT	CULTURAL BARRIERS
• Lack of consensus about severity of environmental problems ♦♦♦♦♦♦♦♦ – Insufficient understanding of relationship to global warming – Lack of publicity of consistent quantification of GHG emission reductions – Little understanding of social costs of hydrocarbons • Lack of general knowledge of H_2 as a fuel ♦♦♦♦♦♦♦ • Need to personalize the hydrogen economy (for the consumer) ♦♦♦♦ – No clear/simple explanation, i.e., how does it work? • Lack of $ dedicated to educating public ♦♦♦ • Too much focus on vehicles • ♦ • Too many parochial interests ♦ – Lack of single focus application to present to public • Too few well-known and knowledgeable champions, i.e., Jay Leno • Lack of news coverage, too few reporters covering hydrogen • Inconsistent nomenclature for H_2 – Calling H_2 an “energy carrier” rather than just another energy source • Almost no understanding of where energy comes from? • No constituency	• Not enough demo $ ♦♦♦♦♦♦♦ – Too few opportunities to see fuel cells in operation • Need ongoing public experiment (model communities)	• Limited educator/teacher training ♦♦♦♦♦♦♦ – Too few structured education programs • Limited distribution channels for existing educational materials K-12	• Lack of consumer pull ♦♦♦♦♦♦♦ • Over emphasizing need to meet business profitability immediately • Too few early adopters with deep pockets • Not enough certainty of long term commitment/funding for H_2 investors	• Lack of patience to keep vision “alive” ♦♦ • Too many other innovative technologies • Consumer inconvenience • Lack of sufficient compulsion to change • Perception of numbers

Hydrogen Education and Outreach
WHAT ARE THE BARRIERS THAT MOST INTERFERE WITH ACHIEVING THE VISION? *(CONTINUED)*

IMPLEMENTATION	POLICY AND IMPLEMENTATION	POLICY	SAFETY
• Too little urgency placed on commercialization ♦♦♦♦ • Lack of standards ♦♦♦ • Too many unproven technologies with potential (OEMs and energy companies not ready to make big investments) ♦ – Too many technologies, not enough $ • Need a critical mass! (Effort can get diluted in the short/mid run) • Slow movement on infrastructure • Timeframe uncertainty • Cost of entry for the public/industry	• Too few sustainable supporting policies ♦♦ • Weak public-private partnership and policy ♦ • Lack of a viable pathway to buy into ♦ • Lack of nearer term vision-tangibles – 10 year focus •	• Inconsistent regulations ♦♦♦♦♦♦ – Lack of understanding among legislative policymakers and regulators – Lack of equitable "rules of the road" – Over-regulation • Lack of monetization of cost/ environmental impact of choices ♦♦♦♦ • Too much entrenched energy interest (traditional means of power) and promotion thereof ♦ • Misdirected incentive funding • Energy choices—impact on foreign policy • Not enough support for taxes to support H_2 development. Gasoline too cheap vs. "real" cost • Lack of long-range planning by government •	• Too much fear of hydrogen safety problems or risks ♦♦♦♦♦♦♦♦♦♦♦ • Lack of understanding danger/safety of current fuels ♦♦♦♦ • Too little effort on business and regulatory communities in FIRE (Financial, Insurance, Real Estate) trades ♦♦ •

*

What Actions Must be Taken to Address the Barriers and Achieve the Vision of H_2?

Business Infrastructure	Education	Funding Advocacy	Marketing	
– Integrate codes and standards (national level) ♦♦♦♦♦♦ – Communicate codes and standards ♦♦♦ – To insurance companies – To operators, e.g., service stations – To builders/contractors/ – architects – To regulators • Communicate a reasonable timeframe (with exit gates) for commercialization • Require accounting (FASB, etc.) of environmental costs/benefits	• Commit long-term resources to educate K-12 and beyond about H_2 energy. – Develop curriculum for K-12, vocational, 4-year engineers, and advanced degree – Include H_2 lesson plan packages with video, demo hardware, and experiments to help educate science teachers and their students – Program for educator training (K-12, vocational) – Have summer workshops for high school teachers (similar to economic group) – Increase number of trained K-12 science teachers – Inventory existing resources • Formulate the path of continuous education – Hydrogen fellowship program – Offer $ for college engineering theses/projects for hydrogen: e.g., vehicle systems, stationary applications, storage, catalysis	– Legislate tax and other incentives to invest in H_2 and fuel cells by 2005 ♦♦♦♦♦♦♦ – Incentivize state-to-state hydrogen partnerships – Create public acceptance for sustained and increasing government funding for the hydrogen economy ♦ – Fund R&D now – Fund the federal government to purchase H_2 equipment (vehicles, power generation, etc.) • Take results from current partnerships and publicize them	• Create consumer demand through all media ♦♦♦♦♦♦♦♦♦♦ – Create cartoons – Product placement in various mediums, i.e., films – Develop community model that identifies stakeholders, products, and infrastructure to transition to a H_2 economy. The model would be transportable, repeatable, nonpartisan, non-parochial – Determine how to incentivize the population to move to a hydrogen economy • Create compelling message or value proposition – Definable goals – Environmental understanding – Gear public toward solution – For the grandchildren – Personalize message – Safety – "Brand" H_2 as clean fuel, freedom fuel – Tie need for H_2 to environmental, economic, and foreign policy	• Develop P&R plan ♦♦♦♦♦♦♦♦♦♦♦♦ – Could be similar EPA/DOE-driven EnergyStar® – Implement a "What is H_2?" campaign – Create H_2 traveling education exhibit – Develop PR strategy, briefing package media kit, Op-ed pieces – Identify public spokespersons, e.g., Jay Leno – Develop trade show and association presentation/booth – Organize coordinated policymaker outreach and education – Invite consumer groups to participate in hydrogen meeting – Create hydrogen education and information center to disseminate H_2 information – Create safety/regulatory information clearinghouse – Educational H_2 programs – Educational video

Hydrogen Education and Outreach

WHAT ACTIONS MUST BE TAKEN TO ADDRESS THE BARRIERS AND ACHIEVE THE VISION OF H_2? *(CONTINUED)*

GOVERNMENT ADVOCACY	DEMOS
• Federal advocacy – build broad business, political, environmental, and higher education coalition to influence U.S. energy policy toward H_2 ♦♦♦♦♦♦♦♦♦♦♦♦ – To earmark public awareness $ – Form Congressional H_2 fellows program – Deliver message that illustrates the consequences of inconsistent regulations – Increase number of Congressional hydrogen advocates – Advocate acceptance and passage externalities – Support appropriations in Congress – Advocate subsidy incentives and policies to bring hydrogen "up to par" with other fuel/power options – Deliver message that promotes continuous path of technology improvement – Analyze/build case for monetizing environmental externalities – Draft externality legislation to impact energy policy • Coordinate all Federal H_2 funding under, for example, OSTP/NSTC for R&D crosscut program ♦♦♦ • Influence regulatory groups for positive outcome on hydrogen initiative • Encourage regional H_2 initiatives/partnerships – League of Cities, Conference of Mayors, National Governors' Association, etc. – Town Hall meetings for legislators	▪ Create a public demo H_2 village ♦♦♦♦♦♦♦♦♦♦♦ – Fund the creation of a H_2 "micro-economy village" for public education—web cast, reality TV, etc. • Launch phased model community projected to showcase H_2 and fuel cell technologies and solutions by 2005 – Get Disney to create "hydrogen world" with hydrogen characters – Get portable fuel cells to market to familiarize public with H_2 fuel – Create PR campaign to support the demo • Advocate the development of a cost-shared program leading to demonstration of H_2 products and services ♦♦♦♦♦♦ – Not enough demos. Develop a "clean H_2" demo program similar to clean coal demo program (to policy makers). – Develop (and fund) cost-shared demos -- stationary fuel cells; vehicular fuel cells; H_2 production, infrastructure, and storage • Sponsor "challenge prizes" for H_2 applications or vehicle achievements

Hydrogen Education and Outreach
Action Plans

Top Vote Getting Actions	Brief Description of the Action	Target Audience(s)	Primary Performing Entities	Primary Funding Entities	Next Steps	Timeframe
Build broad coalition to influence U.S. energy policy on Hydrogen	• Support appropriations • Explain consequences of inconsistent regulations • Support continuous path of technological improvement • Support tax incentives	• Colleagues • Congress/Administration • Stakeholders • State governments	• NHA-Advocacy role and interest • DOE • Industry support and leadership • High-profile sponsorship – Challenge to all to launch a coalition ask for DOE support	• Initial seed $ from DOE – Advocate for demo and authorize $, tax status. • Estimated cost: $2.5-3 million • Grass roots funding	• Identify coalition members • Bring all groups together • Figure out broad message and common policy agenda • Fund organization • Congressional caucus	• Immediately
Develop public relations plan	• Similar to EnergyStar® • Hydrogen "on the map" • Hydrogen campaign • Exhibits • Briefing packets • Public spokespersons • Hydrogen "in your life"	• Everyone	• Coordinated effort • DOE • NHA • New coalition • Fortune 100 • Hydrogen success stories • Hydrogen associations	• New coalition • DOE and EPA • Foundations • States • Grass rots organization (PIRG) • Industry support	• Organize! • Coalition needs to develop PR plan • NHA can begin process • Focus on NEP agenda—hydrogen outreach • Find 3 messages • Reach out to NASEO,NGA, etc.	• Immediately
Create consumer demand interest through all media	• Product placement in films • Community models • Incentives for consumer action	• Everyone	• Coordinated effort • DOE • NHA • New coalition • Fortune 100 • Hydrogen success stories • Hydrogen associations	• New coalition • DOE and EPA • Foundations • States • Grass roots organization (PIRG) • Industry support	• Create awareness through PR	• Immediately

Hydrogen Education and Outreach
ACTION PLANS *(CONTINUED)*

TOP VOTE GETTING ACTIONS	BRIEF DESCRIPTION OF THE ACTION	TARGET AUDIENCE(S)	PRIMARY PERFORMING ENTITIES	PRIMARY FUNDING ENTITIES	NEXT STEPS	TIMEFRAME
Create a public demonstration hydrogen village (10 years out)	• Launch phased model community project • Fund creation of “micro-economy village” for public education • Demos • HO tech development	• Working models • Around country • General public: 1) HO, 2) Technology development • Customers • NAHB • A/E’s • Implementers • HO • Tech development	• HUD • Home builders and contractors • Fannie Mae • NAHB • National Association of Realtors	• HUD • DOE • EPA • Industry • DOT • Foundations • Habitat for Humanity	• DOE Lead • Hawaii project-base • Subcommittee of coalition • DOE solicitation-Buildings of the Future • Support basic R&D – Support for R&D activities – Then, educate and outreach – Raise awareness—temper expectations	• Near- to mid-term (in about 10 years)
Commit long-term resources to K-12→ graduate level education	• Target curriculum—all levels • Educate teachers • Hold summer teacher workshops • Inventory existing resources	• Entire education community • K-12 students • Teacher: NSTA, Dept. of Education • State and local reg. • School districts • Publishing companies	• Coalition • School board associations • Teachers’ associations • Publishers	• Legislatures • Foundations • Private sector support • DOE • NSF	• Inventory resources • Peer review existing resources • Set up teacher training • Try to integrate into existing curriculums	• Immediately

SECTION 8

HYDROGEN SYSTEMS INTEGRATION BREAKOUT SESSION

- **Key messages from breakout sessions:** What are the key barriers and needs you identified from the production, delivery, storage, energy conversion, applications, and education and outreach breakout sessions?
- **Systems integration issues:** What are the crosscutting, missing, and conflicting pieces of information from the breakout sessions that need to be considered by the systems integration group?

Participants:

NAME	ORGANIZATION
Dave Nahmias	HTAP
Bill Smith	Proton Energy Systems
Francis Lau	Gas Technology Institute
Lauren Segal	BP
Chung Liu	South Coast AQMD
Shannon Baxter	California ARB
Matthew Fairlie	Stuart Energy
Douglas Wheeler	UTC Fuel Cells
Seth Dunn	World Watch Institute
Steve Tang	Millennium Cell
Bob Miller	Air Products and Chemicals, Inc.
Revis James	Electric Power Research Institution
Joan Ogden	Princeton University
Catherine Gregoire-Padro	National Renewable Energy Laboratory
Richard Bradshaw	Dykema Gossett, PLLC
Brendan Dooher	National Academy of Engineering

FACILITATOR: Tara Nielson, Energetics, Inc.

KEY MESSAGES FROM BREAKOUT SESSIONS

	BARRIERS	NEEDS

PRODUCTION	• Policy—dealing with (accounting for) fossil fuel externalities
	• Funding
	• Codes and standards
	• Crosscutting R&D on:
	    ○ Catalysts
	    ○ Materials
	    ○ Manufacturability
	    ○ Mass production
	• Technology—carbon sequestration
	    ○ How?
	    ○ How much?
	• "Carbon free energy sources" – Linking renewables / nuclear power and public opinion
		• Demonstrations, demonstrations, demonstrations
		• Policy – have a vision, need a mission – near-term goals!
		• Market pull
		    ○ Product definition—what are the hydrogen solutions?
		    ○ What people think of / know about hydrogen

DELIVERY	• Lack of consensus on total costs – both for hydrogen and alternatives • Codes and standards • Technical maturity of refueling stations • Lack of safety criteria (connects to public expectations) • Chicken or egg—what will be the initial key driving application? ○ Ability to match investment to market • Imbalances between hydrogen supply and demand • Cost of hydrogen technologies • Externality costing • Customer expectations for refueling • Lack of major technology advances	• Demonstrations: initial government funding and government-industry partnerships • Codes and standards development, harmonization • Public outreach, education, access to existing information • Policy, financial incentives • Analyses on lifecycle cost, transition strategies

	BARRIERS	**NEEDS**

STORAGE	• Insufficient funding
	• Lack of codes and standards
	• Energy density too low
	• Lack of education
	• Customer acceptance at risk
	• Lack of major technology advances
		• Breakthrough solutions to energy density issues
		• “Agony neutral” solutions
		• Education on storage safety
		• Materials RD&D
		  o Pressurized storage
		  o Metal hydrides
		  o Chemicals (hydrides, carbon, allenenes)
		• Technology RD&D
		  o Manufacturing
		  o Systems integration
		• Major increase in funding for R&D
		• Raise visibility, expedite, and align interagency activities on codes and standards

CONVERSION	• Lack of coordinated technology development • Oil and gas are too cheap • Lack of a clear, consistent, long-term policy. High degree of uncertainty makes financial markets unwilling to invest	• Clear, realistic understanding of achievable near-term product value propositions • Fuel cell research in materials, interface • New IC engines R&D on electrochemistry, low NOx, efficiency • Expansion and continuation of demonstration projects • Successful incentive mechanism (e.g. California ZEV mandate, wind production)
APPLICATIONS	• No premium for clean technologies. Hydrogen as a fuel does not give financial benefit to user. • Limited incentive for “early adopters” of applications • Cost of hydrogen is high compared to natural gas (where hydrogen cost is low, power cost is low) • Lack of “level playing field” for distributed generation technologies (efficiency, environmental, relative benefits are not fully captured in the market) • Too much reliance on fuel cells while ignoring current technologies • Reliability • Lack of long-term leadership • Chicken and egg issues	• Materials science and basic research • Demonstrations • Bipartisan outreach • National outreach • Local outreach • Government as an “early adopter” (procurement, infrastructure support, demonstrations) • Price parity o Tax credits for oil but no tax credits for hydrogen • Distributed generation policy supports (interconnection standards, codes, etc.) • Optimization in current hydrogen product technologies • Stranded industries “buggy whip” • Uniform tests and evaluation standards • Uniform codes and standards

	BARRIERS	NEEDS

EDUCATION	• Inconsistent regulations, codes and standards, permitting processes
	• Not enough demonstrations (and funding) to educate the public
	• Lack of trained educators
	• Too many technologies—dilutes short-term efforts
	• Fear of hydrogen safety
	• Lack of consensus regarding green house gas impact on environment
	• Lack of consumer pull
	    ○ Sexiness
	    ○ Cost externalities
	    ○ Knowledge
		• Need a religion for hydrogen culture—long term and personalized

INTEGRATION ISSUES

CROSS-CUTTING			MISSING	CONFLICTS

• Policy on external costs of energy (environmental, energy security)
• Basic R&D
  o Coordination across multiple organizations – gaps and overlaps
  o Use R&D resources wisely – so as not to dilute
  o Materials
  o Catalysts
  o Manufacturability
  o Testing
  o Certification
  o Technology storage
  o Durability and reliability
• Timing of subsystem development uneven
• Consumer confidence
  o Technology
  o Dread
  o Acceptance
  o "Why hydrogen?" drivers
• develop method to both integrate this work with previous work and parallel programs
• Development of transition strategies
  o Realigning existing program concentration to match the vision and roadmap
• Regulatory consistency – over time and among agencies
• Technology uncertainties v. sub-technology system alignment
• Applications drive attributes or targets for hydrogen supply chains and infrastructure
	• Integrated hydrogen system demonstration funded by government
	• Global perspective and international markets (benchmark with other government strategies, e.g., EU, Japan, Iceland)
	• Leadership
	  o Setting goals
	  o Policy – societal values
	  o Market – products
	• Investment to upgrade / advance existing technologies, and to launch new technologies
	• More cooperative efforts (e.g., PNGV)
	  o Universities (NSF grants)
	  o National Labs (Fed)
	  o Industry partnerships
	• Systems analysis work
	• Valuation of hydrogen benefits
	  o Energy security
	  o Environmental
	  o What is it worth to consumers, government, society
	• Build on "lessons learned" from other industry roadmaps: nuclear power, biotechnology
	• Limited recognition of mutually reinforcing nature of hydrogen ICE and hydrogen fuel cell technologies
	• Time frames for roadmap process (2010, 2020, 2030) not appropriate—desire for better near-term definition
		• Chicken or egg
		• Demonstrations (technology and education) best way to educate and reduce anxiety (LA hydrogen ICE project)
		• Demonstrate integrated systems – not only technology, also value propositions
		• Codes and standards
		  o Cross-cut everything
		  o Critically important
		  o Single permitting process
		  o Coordinated level
		  o Stationary interconnect
		  o Mobile storage/handling
		• Safety/value
		• Public outreach
		• Price/financial drivers absent
		• Systems approach – need to
		• Advancement of storage technology for production, transport, and mobile, stationary, and portable applications
		• $7,000,000,000,000 in 30 years (Greene, ORNL)
		• Breakthrough technologies and thinking needed
		• Timing – need a short term technology to bridge to longer term (e.g., ICE—fuel cells, DG—pipeline)
		• Balancing and optimizing supply and demand
		• Hydrogen is a problem and an opportunity
		• Government as an early adopter (behaving as a consumer)
			• Need to define value in terms of dollars, environment, electricity system, economic productivity
			• Need to define focus of first application in terms of where greatest value delivered
			• Life cycle / full system benefit-cost analysis: need more, need to reconcile
				• Optimizing production, delivery, storage technologies separately may sub-optimize system or lead to false conclusions
				• Role of and proper balance of leadership from government, industry
				• Does industry focus on a few technologies – prioritize R&D?
				•

SUMMARY OF KEY CROSSCUTTING ISSUES

Codes and standards
Putting and keeping passion behind the vision
Systems analysis
Safety
Chicken and egg—matching supply and demand
R&D component
Development of integration and optimization of systems
Demonstration projects that are integrated
Industry-government demonstration projects and outreach
Government leadership of demonstration projects
Customer acceptance
Policy reflecting external costs and energy security

SECTION 9
CLOSING PLENARY SESSION

Breakout Session Reports

<u>Production</u>
Gene Nemanich, Chevron Texaco Technology Ventures
The top needs identified in the hydrogen production breakout group include:

- Capture and sequester of carbon dioxide in the production process that makes hydrogen and electricity
- Separation of purified hydrogen on a small and large scale
- Cheap small scale reformers
- Codes and standards
- Better large scale gas fires that can use various feedstocks
- Better electrolyzers
- Demonstrations of new technologies, with public and private entities working together because of the risk and expense (e.g., nuclear via Thermochemical)
- Advances in technology (e.g., biological, photolytic, and high temperature separation)
- Funding for programs (e.g., incentives, rewards and penalties relating to long term goals)

Comment from the audience: Clarification regarding the costs of using nuclear power to produce hydrogen – costs should not be misrepresented, as the technology already exists and future efforts can build on this.

Delivery

Art Katsaros, Air Products and Chemicals, Inc.

The methods for delivering hydrogen already exist, however, these methods need to be more cost-effective and better developed. Delivery needs include:

- Codes and standards, and compatibility requirements
- Comprehensive demonstration programs, as there are a lot of new technologies that will be developed
- Solid understanding of various options, especially regarding carbon
- Improved financial incentives (e.g., tax credits)
- Better understanding of the transition to a hydrogen economy
- Current infrastructure—how much is convertible for dual-use or how much will be built out for a new hydrogen system?
- Better understanding of delivery system options
- Getting better access to existing information

Storage

Alan Niedzwiecki, Quantum Technologies

Hydrogen storage technologies are a critical component to the success of achieving a hydrogen economy. Storage crosses many boundaries and is part of the big pictures. There are early adopters of the technology, but they are not as developed as they need to be. The top needs identified in the hydrogen storage breakout group include:

- Allow new technologies to improve and move forward
- Codes and standards—champions, developers, and harmonizers
- Finding a way to get from research and development to mass commercialization—the education component is a big challenge
- Long term strategies for recycling storage devices

Energy Conversion

Mike Davis, Avista Labs

The energy conversion group found that roles will need to be addressed as everyone moves forward. There is tension between the private sector's need to move quickly, and the long-term transition for the nation – this caused debate. Regarding timeframes for the identified next steps, activities have to be accelerated in order to get products into the marketplace. The top needs identified in the energy conversion breakout session include:

- Codes and standards (e.g., product safety and performance standards, jurisdictional issues)
- Research and development for fuel cells and internal combustion engines—there needs to be a broad effort on materials, electrochemical, and interface R&D, which feeds into product development and demonstrations
- Cost reduction, reliability, productivity, durability
- Demonstrations – the challenge is making them valuable. They need to involve customers, have evaluations and feedback, and have realistic expectations.
- Institution-building
- Existing work needs to be shared before moving forward and reinventing the future.

Applications

Frank Balog, Ford Motor Company

This breakout session focused on the components and systems requirements for mobile and stationary end-use applications for hydrogen. Most of the time was spent discussing mobile applications.

Key barriers the group identified include:

- Infrastructure (e.g., fuel, affordability, widespread use)
- Customer acceptance (e.g., need a reason to switch from current system)
- Lack of technology development strategies
- Leadership void (e.g., public policy)
- Technological shortfalls (e.g., onboard storage)

Key needs the group identified include:

- Hydrogen storage technologies
- Conversion (e.g., low cost fuel cell stack with improved reliability and durability)
- Technology-based codes and standards
- Government leadership (e.g., government as customer and infrastructure developer) with industry support
- Demonstrations
- Community-based clustered applications (e.g., hydrogen centers for mobile and stationary applications)
- Short-term end use technologies (fuel cells and combustion engines) to stimulate the infrastructure development
- Promotion of local demonstration pockets and their application on a national scale (e.g., California Fuel Cell Partnership)
- Increased sense of urgency
- Adequate funding, coordinated with the market and government
- Outreach and education

Public Education and Outreach

Jeff Serfass, National Hydrogen Association

For the purposes of this breakout session, the public included all audiences – 22 different audiences were identified, along with the messages and actions that need to be targeted to the various populations.

The top barriers identified in this breakout session include:

- Safety fears
- Lack of good examples to latch onto
- Lack of consensus in terms of environmental problems and hydrogen as a fuel
- Lack of training
- Lack of consumer pull
- Lack of monetization of environmental risks

Actions that the participants identified to address these barriers:

- Build a broad coalition to advocate energy policy—this would include participation at the state and local levels, and would involve advocacy on appropriations, regulations, continued paths of technology improvements, legislation, and incentives. There is a sign on sheet for volunteers.
- Organize public relations and education campaigns, which include briefings, identifying spokespersons, creating an Energy Star®-type program, identifying a convener for the various efforts, and having the Department of Energy seed the efforts
- Improve consumer awareness to create demand and facilitate understanding

- Initiate product placements in films
- Create a compelling message that stresses safety
- Brand hydrogen, with an environmental spin
- Create a long-term education plan that trains teachers at all educational levels

Messages that were identified:

- Freedom Fuel
- Tie hydrogen to fast-moving train
- Hydrogen is clean and adds new options
- Hydrogen is everywhere—it's right in your back yard
- Hydrogen "economy" is not a great term for resonating with the public
- Safety needs messaging—cool, hip, use pop culture
- Hydrogen provides independence, is cost-effective, and is the environmental choice
- Hydrogen works – it's big business today

<u>Systems Integration</u>

Joan Ogden, Princeton University

The top crosscutting themes identified during the systems integration breakout session include:

- Government leadership is needed to put the passion in the vision
- Policies are needed that reflect the external costs of energy and that are consistent with energy security
- Codes and standards development needs to continue
- Safety
- Consumer acceptance
- Research and development in technical areas needs to continue—industry will select out and put successful technologies into integrated systems. Looking at the system as a whole is important.
- Transition strategies need to be put into place, with consideration for the full costs to society—analysis needs to be used to think through all of this.
- There is a chicken and egg issue and supply and demand need to be matched
- There is a need for public-private partnerships to maximize demonstrations and what is learned from them
- This is a long-term vision, but we need to take steps now to achieve it

Audience Comments

Regarding integration, life cycle analysis across industry segments needs to be conducted—please consider this for the integration chapter.

What if the unthinkable happens – an oil crisis – please consider including a contingency plan for producing hydrogen.

It is important to keep in mind the importance of international markets – they are a big aspect. Perhaps the vision and roadmap could be applied globally.

Powerful integration could occur between stationary and mobile markets – an analysis is needed.

Enabling markets are needed – they can happen through government-industry partnerships.

Regarding leadership issues, the superconductivity effort can be an example of how to advance the hydrogen goal.

Regarding integration – leadership will come from industrial and entrepreneurial entities. Industry cannot look just to government for leadership. A "do-able" pathway needs to be established and then follow-through is needed. The roadmap should include what is "do-able" and then improvements should be made in those areas.

Next Steps

Rich Scheer, Energetics, Inc.

- Thanks to everyone for sharing his or her good ideas and for your hard work – but we have just begun.
- After the workshop ends the notes and ideas will be documented and will be posted on the web for comment. These notes will be used to write the chapters for the roadmap document.
- I urge you to comment on the materials and provide your input.

Closing Remarks from Department of Energy Officials

Robert Dixon, Office of Energy Efficiency and Renewable Energy

- There seems to be a lot of enthusiasm here, I'm pleased that that is the case. Thanks to the industry leaders and Department of Energy colleagues for heading up this effort.
- It is one of my personal dreams to see the hydrogen technology portfolio flourish.
- During the presentations there were several references to leadership, and the Department of Energy leadership is here today. Please welcome David Garman, Assistant Secretary for Energy Efficiency and Renewable Energy.

David Garman, Assistant Secretary, Energy Efficiency and Renewable Energy

- One of my purposes here today is to thank Secretary Abraham. He challenged us to leap frog the technological status quo for environmental benefits. He has created a collegial Department of Energy and a team that is working together and with the private sector to develop new ideas.
- Government leadership needs to go hand in hand with public, Congressional, and boardroom plans. Leadership needs to take place inside and outside of government.
- Thanks also to Robert Card. Mr. Card has taught us that passion is important but not enough, and has asked us tough, uncomfortable questions as we make plans about the nation's energy future. He has reminded us of the link between taxpayer dollars and America's future.
- Thanks also to Kyle McSlarrow for his work behind the scenes in support of hydrogen energy development. He helped give hydrogen its role in transitioning markets and the nation's energy future. He made an impression on the President, and has since been nominated to be the Deputy Secretary of the Department of Energy. Please welcome Kyle McSlarrow.

Kyle McSlarrow, Chief of Staff for the Secretary of Energy

- I would like to compliment everyone here on work well done. This effort will take time, and will not end after these two days.
- Last year during the planning process for the National Energy Policy, there was a traditional debate over energy production versus conservation. We realize that this is not a zero sum game – America can do both with the entrepreneurial spirit and genius we have in this country. We have been asked to leap frog this old, tired, stale debate and start thinking outside the box.

- Hydrogen is just one focus in the National Energy Policy, but the Secretary has spoken about hydrogen more than any other subject mentioned in the Plan. The greatest opportunity and the biggest legacy he can leave would be to focus on incremental changes that will end up being large changes to society and our economy in the long-term future.
- I view this like a revolution—the scale of this effort is staggering, and everyone will need to be prepared before it can be fully launched. We have not seen change on this scale for several generations. I'll turn the microphone back over to Mr. Garman for closing remarks.

David Garman, Assistant Secretary, Energy Efficiency and Renewable Energy

- There are two paths we need to follow: research and development, and public outreach to capture the imagination of the American people. This will be a long journey and process, and the Department of Energy will work with you as we move forward.
- Thanks to all of you.

Section 10
List of Participants

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