Cooperative Agreement DE-FC36-00GO10605
Hydrogen Technical Analysis
Dissemination of Information

Final Report

December 31, 2005

Prepared for

DOE GOLDEN FIELD OFFICE

1617 Cole Boulevard
Golden, Colorado 80401-3393

Prepared by:

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March 20, 2006

Mr. Douglas Hooker
Project Engineer
U.S. Department of Energy
Golden Field Office
U.S. Dept. of Energy
1617 Cole Blvd.
Golden, CO 80401-3393

Re: Final Report for Cooperative Agreement DE-FC36-00GO10605, Technical Analysis -- Dissemination of Information

Dear Mr. Hooker,

SENTECH, Inc. is pleased to submit to you our final report on Cooperative Agreement DE-FC36-00GO10605, Technical Analysis -- Dissemination of Information.

SENTECH values the opportunity to work collaboratively with the DOE GFO on the Hydrogen Technical Analysis activities, disseminating information on hydrogen energy technologies and the promise that they hold. The federal hydrogen development program has expanded significantly since this award was made and SENTECH and its partners on these activities are proud to have played our part. Additionally, I have greatly appreciated your assistance and guidance on matters associated with this collaborative agreement and the federal hydrogen development programs in general.

Feel free to contact me as needed to discuss this report or any thing else with regard to this closed-out agreement.

Sincerely,

SENTECH, Incorporated

George Kervitsky, Jr.

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Table of Contents

1.0 Introduction

The following is a final report for activities conducted by SENTECH, Incorporated (SENTECH) over the period of performance of cooperative agreement DE-FC36GO10605. This contract, awarded to SENTECH in June 2001, was in response to competitive solicitation DE-PS36-00GO10482-02 by the U.S. Department of Energy (DOE); under statement of work *Area 3 – Dissemination of Information.* The work conducted and completed under this cooperative agreement has been conducted in 2 phases as presented in this document. The first phase included the activities, which were presented in our originally proposed set of activities, and a second, follow-on phase, which was awarded in early 2003.

SENTECH is a small energy and environmental consulting firm providing technical, analytical, and communications solutions to technology management issues. Its staff of scientists and engineers works closely with marketing and communications specialists to develop creative technical and communications strategies for complex scientific and technical issues. SENTECH has a corporate commitment to the implementation of clean, renewable energy options including hydrogen. SENTECH honors this commitment by offering both financial and in-kind cost share to the activities proposed here and through the use of a highly qualified and dedicated team of staff and consultants that will implement an effective and long-term hydrogen information dissemination program. Over the period of performance on this cooperative agreement, SENTECH also received in-kind cost share from key collaborators, including the National Hydrogen Association; National Fire Protection Association; and Dr. Robert Reeves, Professor Emeritus, Rensealler Polytechnic Institute.

The activities proposed by SENTECH focused on gathering and developing communications materials and information, and various dissemination activities to present the benefits of hydrogen energy to a broad audience while at the same time establishing permanent communications channels to enable continued two-way dialog with these audiences in future years. Effective communications and information dissemination is critical to the acceptance of new technology. Hydrogen technologies face the additional challenge of safety preconceptions formed primarily as a result of the crash of the Hindenburg. Effective communications play a key role in all aspects of human interaction, and will help to overcome the perceptual barriers, whether of safety, economics, or benefits.

As originally proposed SENTECH identified three distinct information dissemination activities to address three distinct but important audiences; these formed the basis for the task structure used in phases 1 and 2. The tasks were:

1. Print information -- Brochures that target the certain segment of the population and will be distributed via relevant technical conferences and traditional distribution channels.
2. Face-to-face meetings -- With industries identified to have a stake in hydrogen energy. The three industry audiences are architect/engineering firms, renewable energy firms, and energy companies that have not made a commitment to hydrogen
3. Educational Forums -- The final audience is students - the future engineers, technicians, and energy consumers. SENTECH will expand on its previous educational work in this area.

The communications activities proposed by SENTECH and completed as a result of this cooperative agreement was designed to compliment the research and development work funded by the DOE by presenting the technical achievements and validations of hydrogen energy technologies to non-traditional audiences. These activities were also designed to raise the visibility of the DOE Hydrogen Program to new audiences and to help the program continue to advance its mission and vision. We believe that the work conducted under this cooperative agreement was successful at meeting the objectives presented and funded over the period of performance.

During Phase 1, SENTECHs activities resulted in the development and distribution of two glossy brochures that target the on-site distributed generation and public transit markets for hydrogen energy technologies; face-to-face industry outreach meetings with various firms with an interest in hydrogen energy, but who may not have made a commitment to be involved; and implementation of two educational forums on hydrogen for students - the future engineers, technicians, and energy consumers. The educational forums were conducted with in-kind cost-shared contributions from NHA and Dr. Robert Reeves, Professor Emeritus, Rensealler

During Phase 2, SENTECH activities initially were focused on the development of additional brochures and the development of a series of training modules. This set of information dissemination activities built on the experience demonstrated in our phase one activities, and focused the effort within two critical issue areas facing the development of hydrogen as an energy carrier – effective communications and information dissemination on codes and standards. SENTECH joined with the National Fire Protection Association (NFPA) to scope out the training modules and identified a series of 12 that could be used to train a variety of audiences.

The NFPA is an international nonprofit corporation, which has developed a reputation as a worldwide leader in providing fire, electrical, and life safety to the public since 1896. Its membership totals more than 75,000 individuals from around the world and in more than 80 national trade and professional organizations.

2.0 Activities and Results

Phase 1 Activities

Task 1 – Communication Documents:

This task involved researching and writing two glossy brochures, as well as distributing the brochures to the public.

Brochure One: Presenting the Hydrogen Energy Option to Industry

SENTECH identified two timely communications pieces that will take the form of glossy, informational brochures. The first, aimed at corporate decision-makers in Fortune 500-type companies, presented hydrogen as an option for distributed power generation applications, particularly on-site power generation at industrial or commercial facilities. The brochure, which is contained in the appendix also capitalized on the corporate interest in greenhouse gas emission reductions.

The brochure employed photographs, diagrams, graphs, and tables to present information on system components, system integration, economic data, siting considerations, and other issues. This brochure was completed in time for distribution at the GlobeEx 2000 Conference and Tradeshow to be held in Las Vegas, Nevada in late July 2000. The conference and tradeshow showcases the latest advancements in alternative, sustainable, and renewable energy technologies. This brochure was distributed by SENTECH with the *Hydrogen Power* booth serving as the backdrop. A PDF version of the brochure file was created and made available on the SENTECH website for a period of time and distributed widely after the supplies of the print version were depleted

Brochure Two: Case Study of Gaseous Fuel Infrastructure

The second brochure presented a case study of a public transit agency's successful transition from a liquid fuel infrastructure to a gaseous infrastructure in preparation for the final renewable hydrogen infrastructure. There are a number of perceived barriers to the use of gaseous fuels, including hydrogen by transit operators. Barriers such as economics, safety, and uncertain benefits can be easily dispelled through effective communication of successes at transit agencies implementing gaseous fuels. This brochure presented how technical and regulatory barriers were addressed, how technicians and drivers were trained to handle gaseous fuels, how partnerships were formed with public and private entities to expand the use of gaseous fuels, and how public perception about safety was handled through education. SunLine Transit Agency served as the case study subject and SENTECH worked closely with SunLine to gather the appropriate information on measured economics and benefits, and acquire photos and other graphical elements for the production of a glossy brochure. This brochure was completed and presented at the 2001 Clean Cities Conference. A PDF version of the brochure file was created and made available on the SENTECH website for a period of time and distributed widely after the supplies of the print version were depleted

Task 2 – Industry Meetings:

SENTECH successfully conducted 13 industry outreach meetings for the DOE Hydrogen Program between 1994 and 2001. Over that time, the purpose and scope of the meetings changed in response to new programmatic direction and advancements made in hydrogen and related industries. The 2000-2001 meetings changed the direction of this effort to reach new industry audiences. The ultimate purpose of this effort was to educate and initiate a continuing dialog in the effort to promote hydrogen energy and address perceptual barriers.

In Portland Oregon, November 2000 SENTECH meet with NW Natural, a Natural gas supplier in the region, members of the Portland Energy Conservation Institute; representatives of Texler and Associates, consultants, a representative of the Willamette Valley Clean Cities Organization; and a presentative of TriMET, the regional transit agency. In Hawaii, SENTECH meet with representatives of the Gas Company, Hawaiian Electric Company, PUNA Geothermal. This effort resulted in tremendous interest in the development of hydrogen as an energy carrier and legislation to roadmap Hawaii's energy future. In Colorado, SENTECH meet with Dr. Amory Lovins and representatives of HyperCar, Inc. In the Washington Area, industry meetings included representatives of Mitsubishi Research Institute, representatives of the National Fire Protection Association, the International Code Council, and RTKL an engineering and architecture firm with offices around the World.

Task 3 – Educational Forum

SENTECH has had an integral role in the organization and implementation of student educational forums, and has provided live chemistry show and hands-on laboratory elements at these meetings. A copy of the chemistry show presentation can be found in Appendix 2. SENTECH worked with Mary Rose de Valladares of MRS Enterprises, who has been directly involved in the organization and implementation of the last five NHA student invitationals, to conduct two educational forums during the contract period. After five years of nearly the same routine, SENTECH worked with MRS Enterprises to overhaul the educational forums, and identify candidate middle schools in the Washington, DC area for the in-school educational forum. All schools and teachers involved in the educational forums were provided materials package that included copies of the *Mission H2* CD-ROM and accompanying *Teacher's Workbook*, and the *Clean Corridor Curriculum* to allow for an introduction to hydrogen through preparatory course work.

Phase 2 Activities

We learned during our initial award activities that the challenges to the old notion that hydrogen represents a long-term energy option must be accompanied by a more aggressive and comprehensive information exchange. More work is required to begin breaking negative perception of hydrogen, so that as it moves beyond niche markets to broader applications, hydrogen will be embraced rather than feared. Hydrogen's introduction into consumer markets requires safety and risk assurances to convince the general public and doubting public safety advocates that hydrogen can be safely managed like other energy carriers. As such, SENTECH decide to focus phase 2 activities to ensure that the resulting products meet the needs of the various certified codes, standards, and safety personnel installed throughout the country.

SENTECH initially intended to pursue two of the three original tasks, but in the end all resources were directed at the original Task 3, Educational Forums. Our approach was to aggressively address the hydrogen codes, standards, and safety issues and prepare information to be disseminated to a focused constituency intimately linked to the general public.

TASK 3: Educational Forums – The Development of Hydrogen Codes, Standards, and Safety Training Modules and Materials

Unlike SENTECH's previous educational forum products, which focused on presenting information to middle and high school students, the phase 2 efforts focused on the education of our nation's current generation of fire and safety engineers, technicians, and other key stakeholders on hydrogen codes, standards and safety issues. The Hydrogen Codes, Standards, and Safety Training Modules and Materials developed as a result of this task are intended to become part of various hydrogen safety training forums. SENTECH collaborated with the National Fire Protection Association (NFPA) to scope out the 12 possible Hydrogen Codes, Standards, and Safety Training Modules.

In the end, funding constraints resulted in the down selection of 7-8 individual modules to allow the content to be adjusted to accommodate the needs of its standardized training regiment, yet be flexible as needed for use in customized, contract training. The development of other training materials and module workbooks, planned as part of Phase 3, were cancelled. The modules developed using Powerpoint software, are included in Appendix C. A listing of the modules prepared under this cooperative agreement is provided below. The following page lists all the modules originally scoped out with NFPA, and initially researched. It also denotes which modules were not completed due to funding constraints.

	Description
Module 1	Introduction to training modules
Module 2	Properties and applications of hydrogen
Module 3	Regulations, codes, and standards for transportation
Module 4	Regulations, codes, and standards for Stationary Fuel Cells
Module 5	Storage and piping
Module 6	Dispensing/transfer operations.
Module 7	Emergency response procedures
Module 8	Hazard Analysis Procedures (failure modes and effects analysis).

Hydrogen Safety, Codes and Standards, Training Modules

	Description
Module 1	**Introduction to training modules**
Module 2	**Properties and applications of hydrogen**
Module 3	**Regulations, codes, and standards for transportation**
Module 4	**Regulations, codes, and standards for Stationary Fuel Cells**
Module 5	**Storage and piping**
Module 6	**Dispensing/transfer operations.**
Module 7	**Emergency response procedures**
Module 8	**Hazard Analysis Procedures (failure modes and effects analysis).**
Module 9	Personnel training for installation and operations (including emergency response training, operating procedures, training intervals, and certification). There may be some overlap in this area with a Swain proposal regarding activities at the HAMMER facilities out in Richland, Washington. Check with the folks out at Sunline transit to see what has been developed for training staff on the use of hydrogen.
Module 10	Facility inspection for enforcement officials. Key word inspections. What will enforcement officials be looking for?
Module 11	Facility siting example (smaller group exercises)
Module 12	Intro and Emergency response scenarios (smaller group exercises). Eventually it will leak and the incident will need to be responded to and resolved/contained.
Module 13	Operations history (overview of existing facilities and their safety record). We will need to work with and get information from manufacturers such as AP&C and the facility owners to obtain the info needed for this section. We will need to gather information on regular maintenance requirements and problems. Explore problems with the development of natural gas stations. Talk to Henry Sief on this matter. Also touch base with Gary Howard of Stewart Energy to discuss their equipment installations. Maybe dovetail this with the SENTECH case study being done of the Las Vegas facility (check SOW). Maybe consider the assembly of possible fault trees?

APPENDIX A:
PHASE 1 Print Materials

Technology Brochures

TRANSIT

ADDRESSING TRANSIT AGENCY CONCERNS

ECONOMICS — Fuel cell buses equipped with the XCELLSIS engine and Ballard fuel cell stacks are expected to be cost competitive with CNG buses, both in terms of capital cost and operating costs, after approximately 1500 units have been produced.

Source: Clearing up: Zero-Emission Buses in Real World Use. A Report on the XCELLSIS/Ballard Phase 3 Fuel Cell Bus Program, 2001.

PERFORMANCE — The demonstration of a hydrogen fuel cell bus in Chicago won rave reviews from passengers and drivers on the buses' smooth ride, low vibration, and reduced noise. The 275 horsepower (205 kilowatt) fuel cell engine has a range of 250 miles without refueling. The fuel cell bus meets the operating performance of a diesel bus, while emitting only warm, moist air.

MAINTENANCE AND TRAINING — Hydrogen fuel cell buses operate just like diesel buses from the driver's point of view. Refueling and maintenance does require additional training; however, the experience of British Columbia (Canada) Transit in its demonstration of fuel cell buses in Vancouver proved those obstacles easy to overcome. According to Operations Manager Stan Sierpina, "It was easy to use and our staff were able to learn the fueling process with ease."

ON BOARD

1 case study

Munich (Germany) International Airport Hydrogen Project

Perhaps the most talked-about hydrogen project is the world's first public liquid and gaseous hydrogen refueling station at Munich Airport. The fully-automated liquid service station will fuel several hydrogen-driven VIP passenger cars, while the compressed gaseous station will power transport buses. An electrolysis plant will generate the hydrogen on site.

More information: www.hydrogen.org/h2muc/introe.html

THE FUTURE IS NOW

2 case study

SunLine Transit Agency Palm Desert, CA

debuted its integrated hydrogen production (including renewable), storage and fueling station in 2000. The station dispenses both pure hydrogen and Hythane® (a mixture of hydrogen and compressed natural gas). Currently the station provides fuel for three SunLine buses — the agency intends to begin converting all its natural gas buses to hydrogen fuel cell buses by 2002 - 2003.

More information: www.sunline.org/altfuels/suninh2.htm

For more hydrogen information:
www.eren.doe.gov/hydrogen
www.HyWeb.de/index-e.html

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Imagine
riding
the bus
of the
future

It is **QUIET**,
as there is no engine.

It is **CLEAN**,
as it produces no exhaust.

It is **RELIABLE**,
as it is simple to maintain.

This is a hydrogen energy future.

INTRO

TRAFFIC CONGESTION IS DRIVING AMERICANS TO MASS TRANSIT. On an average weekday, the nation's transit system carries more than 27 million riders. In 1998, transit provided more than 8.1 billion trips, 59 percent of which by bus.

BUSES ARE MORE FUEL EFFICIENT THAN INDIVIDUALS DRIVING THEIR OWN CARS. However, the average diesel bus (more than 90% of today's fleet) produces 280 times more soot and 50 times more smog than a car. Natural gas buses are better, but a hydrogen fuel cell bus is the best choice – zero soot or smog contribution.

NOT ONLY DO HYDROGEN FUEL CELL BUSES RESULT IN CLEANER AIR, but they can also save money. The Union of Concerned Scientists estimates that in Los Angeles, for example, the emissions saved over the life of a natural gas bus are worth $56,000 in avoided costs for controlling industrial air pollution – costs that businesses and consumers would otherwise pay to meet clean air requirements. A hydrogen fuel cell bus could save $151,000 in these costs over its lifetime.

Source: Unlinked passenger trips. Federal Transit Administration 1998.

SOLUTION

Hydrogen is NON-TOXIC, and produces only water and heat when consumed in a fuel cell.

Hydrogen can be produced with renewable energy for a POLLUTION-FREE energy source.

Hydrogen is SAFE, and can be handled under most existing codes and standards.

THE HYDROGEN PATHWAY

1 PRODUCTION

First, hydrogen must be separated from a hydrogen-containing source, such as methane (natural gas) or water.

2a REFORMING

Obtaining hydrogen from methane requires chemical separation of the hydrogen (H) from methane (CH_4).

2b ELECTROLYSIS

Splitting water into hydrogen and oxygen through a process called electrolysis requires electricity. Renewable resources such as wind or solar could generate this electricity pollution-free.

3 DISTRIBUTION

Like natural gas, hydrogen can be transported as a compressed liquid or gas via pipeline or truck.

4 STORAGE

Vehicles can store hydrogen in pressurized tanks similar to those used for natural gas and propane.

5 UTILIZATION

Combining hydrogen with oxygen in a fuel cell produces electricity with water vapor as the only by-product.

VISION

"Delivery of electricity and hydrogen as final energy source would practically eliminate emissions at the point of end use, and allow carbon removal and storage from the energy sector itself."

— Technologies, Policies and Measures for Mitigating Climate Change, IPCC Technical Paper I, November 1996

"With public education and garage-style handling, hydrogen can be at least as safe as today's fuels."

— The Economist, The fuel cell's bumpy ride, March 22, 2001

SOLUTION

HYDROGEN FUEL CELLS ARE:

- Emission-free and efficient
- Modular for changing power needs
- Low maintenance
- Uninterruptible/premium power
- Low noise/small thermal footprint
- Flexible in siting

AN ON-SITE HYDROGEN FUEL CELL gives businesses control over their power supply. Besides insurance from power outages, a hydrogen fuel cell offers protection from peak energy demand rates and can reduce facility energy service costs by 20-40% in large-scale building systems.

DOD FUEL CELL PROGRAM

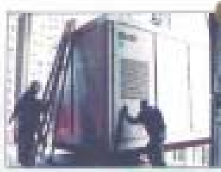
30 phosphoric acid fuel cell (PAFC) units were installed at Department of Defense (DoD) sites from 1993-1997, most are still in use today. Fuel cell sites span 17 states, from Alaska to Florida, in building applications ranging from hospitals to central plants to barracks. The fuel cells vary in use as well, providing space heat, back-up power, and hot water among other uses.

SITE PERFORMANCE

Naval Station Newport	(1/95-12/99)
Average Output:	153 kW
Efficiency (electric and thermal):	42 %
Availability:	82 %

For more information:
www.dodfuelcell.com/index.html

IN USE TODAY



1 case study

4 TIMES SQUARE, NEW YORK, NY

4 Times Square in New York City is one of the first office buildings in the U.S. to be powered almost entirely by alternative energy sources. The 48-story skyscraper generates electricity from two 200-kW phosphoric acid fuel cells operating on pipeline natural gas. The natural gas is reformed to produce hydrogen for the fuel cell. Additionally, the building's photovoltaic (PV) skin uses thin-film PV panels to generate electricity.

2 case study

FIRST NATIONAL BANK, OMAHA, NE

The 200,000-square-foot technology center at First National Bank of Omaha processes credit card orders 24 hours a day, seven days a week. Even brief power interruptions can take down a computer system that requires costly hours to recover. So the bank installed the most reliable power source it could find: a fuel cell system that leaves the company exposed to the utility grid for just 32 seconds per year. "The availability of power is our biggest concern," said John Lehning, vice president and director of construction and leasing for FNBO. "Our system is 99.9999 percent (reliable), which is a quantum leap forward."

For more hydrogen information:
www.eren.doe.gov/hydrogen

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You've

INVESTED in your employees,

MAXIMIZED production efficiency,

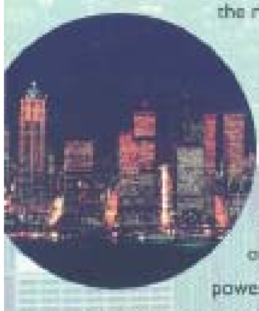
and **REDUCED** raw material costs . . .

. . . BUT WHAT WILL YOU DO

IF THE POWER GOES OUT?

RELIABILITY

THE PRICE OF ELECTRICITY may appear on a balance sheet, but what about the cost of a power outage? Demand for electricity is growing faster than existing and projected capacity can supply, and the result is power outages and brownouts. Domestically, the projected need is for 1.7 trillion kilowatt-hours of additional electric power over the next two decades.



POWER OUTAGES AND FLUCTUATIONS cost the U.S. nearly $30 billion a year in lost production, according to the U.S. Department of Energy. Even slight variations in power quality can disrupt the delicate manufacturing processes involved in making semiconductors and other advanced products. The cost of these power "events" is likely to rise, as computer-related electrical use will grow to 50% of power use in the next 20 years.

The California Manufacturing and Technology Association recently estimated a summer of blackouts could cost the state $21 billion and 136,000 jobs as manufacturers curtail production and retail stores suffer a slowdown.

During the western power outages in 1998, nearly 90% of small U.S. businesses reported experiencing at least one power outage. The yearly average was three outages, costing each business approximately $7,500 per day.

HYDROGEN

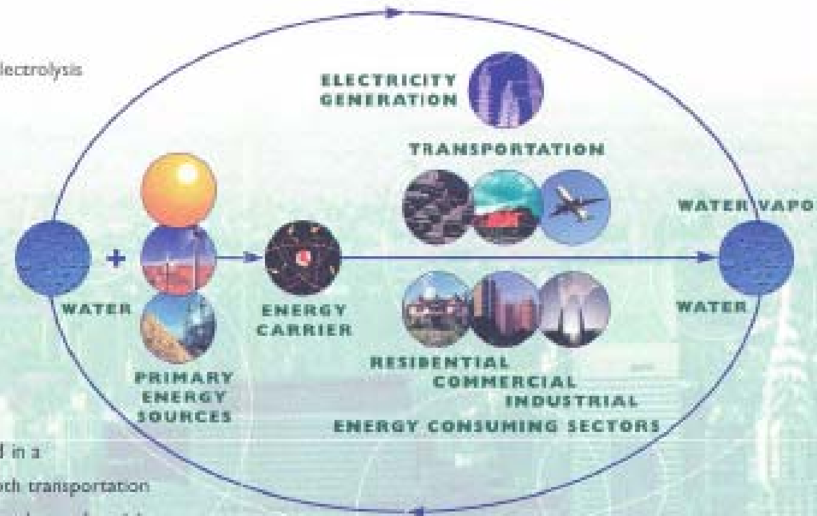
HYDROGEN IS CLEAN

When Hydrogen is produced by electrolysis (water splitting) using renewable energy sources, it becomes a closed-loop energy process producing only water and heat as by-products.

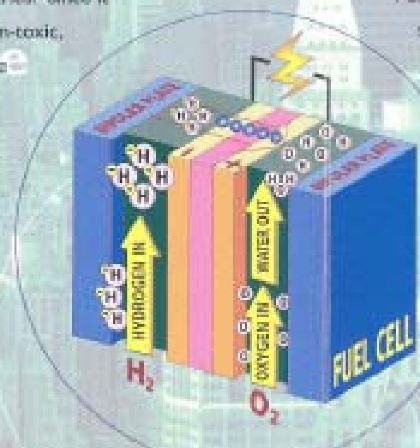
HYDROGEN, AN ENERGY CARRIER, CAN THEN BE STORED in tanks or pipelines and later used in a fuel cell to create electricity for both transportation and stationary applications. As it produces electricity, the fuel cell reunites the hydrogen with oxygen from the air to regenerate the water once used by the electrolyzer to make hydrogen.

HYDROGEN HAS A PROVEN SAFETY RECORD through its everyday uses in the chemical, refining, and space industries. Since it is lighter than air and non-toxic, hydrogen is safer in some respects than many of today's fuels.

FUELCELLS



THERE ARE SEVERAL TYPES OF HYDROGEN FUEL CELLS: phosphoric acid (PAFC), proton exchange membrane (PEM), and alkaline. PAFC is the only kind now commercial, but PEM is in demonstrations for stationary applications. The PEM fuel cell uses a thin platinum catalyst layer to separate the hydrogen fuel into electrons (negative charge) and protons (positive charge). The membrane (pink layer at left) allows the protons through but forces the electrons around the circuit, thus creating the electrical current. With the addition of oxygen from air, the regenerated hydrogen (proton plus electron) and oxygen combine to produce water.



APPENDIX B:
PHASE 1 Industry Meetings

Sample Meeting Presentation

HYDROGEN STAKEHOLDER OUTREACH MEETINGS 2001

SENTECH, Inc.

U.S. Department of Energy

MEETING INTRODUCTION

MEETING GOALS

- Create an on-going dialogue to benefit the program and its stakeholders
- Enhance stakeholder role and participation
- Identify commercially viable opportunities for collaborations and joint development/ demonstration projects

MEETING PURPOSE

- Assess stakeholder's position with respect to hydrogen in the energy market
- Identify regional issues that may impact (negatively or positively) the introduction of hydrogen to the energy market
- Assess perception of infrastructure, regulatory, and awareness barriers to the introduction of hydrogen in energy markets
- Gauge perception of effectiveness of federally funded hydrogen efforts

MEETING PERSPECTIVE

- **In 1994-1996 and 1999, the DOE Industry Outreach Program visited over 35 companies/organizations**
  - Meetings successfully increased industry participation in DOE Hydrogen Program
- **When focus shifted to analytical, R&D, and technology validation activities, DOE curtailed industry outreach**
- **Currently, the hydrogen business climate and market have seen a dramatic shift. Consequently,**
  - DOE Hydrogen Program has grown and will support $27 million in Hydrogen RD&D in FY 2001
  - DOE is interested in gaining fresh perspective from a broader stakeholder group on perceived technical and economic barriers and recommendations for the expanded DOE program

MEETINGS HELD DURING 1994-1996 & 1999

Chemical Manufacturers
American Air Liquide
Air Products & Chemicals
AlChe
Dow Chemical
DuPont
Monsanto
Praxair

Integrated Energy Co.
BP Amoco
ExxonMobil
Texaco

Transportation
Chrysler Corp.
Detroit Diesel
Ford Motor Company
General Motors

Utilities
American Gas Association
ENRON
New York Power Authority
Northern States Power
Pacific Gas & Electric
SMUD
U.S. Generating

Insurance
Factory Mutual Research Corp.
Hartford Steam Boiler

Engineering Services
Bechtel
Foster Wheeler

Equipment Mfgs.
Aerojet
Energy Conversion Devices
H-Power
International Fuel Cells
Molten Metal Technologies
Teledyne Brown
Westinghouse

Regulatory
CA Air Resources Board
CA Energy Commission
SQAMD

Advocacy
American Gas Assoc.
National Hydrogen Assoc.
National Petroleum Refiners Assoc.

BENEFITS OF INVOLVEMENT

- Get access to and influence direction of government funded R&D projects
- Leverage R&D investments with federal funding for mid- and long-term, high-risk technology development and validations
- Accelerate entry into near-term niche markets
- Obtain a competitive edge in the emerging hydrogen energy market (both domestic and international)
- Industry support and collaboration can help expand the DOE Hydrogen Program, creating increased opportunities for industry

MARKETING BUSSINESS PERSPECTIVE

HYDROGEN MARKET & BUSINESS PERSPECTIVE

- Technology advances in fuel cells and small-scale production have improved; cost competitiveness is currently attainable in niche applications
- Auto industry and others are investing substantially to position themselves for future market success (DaimlerChrysler, Ford)
- Restructuring of electricity industry is creating consumer choice and new market opportunities for distributed power (Plug Power, others)
- Energy producers have embraced inevitability of finite fossil fuels and environmental impacts (BP Amoco, ARCO, Shell Hydrogen)
- Environmental regulations (ZEV mandates, etc.) are creating/driving market opportunities (CA Fuel Cell Partnership)
- Climate change impacts are becoming recognized by domestic and international policy makers

NEAR-TERM NICHES

- Hydrogen slip streams
- Opportunity fuels
- Fleet vehicles / urban transportation

REGULATIONS CREATE MARKET OPPORTUNITIES

- Federal and state ZEV mandates

- New EPA diesel rules

- Utility restructuring

DISTRIBUTED POWER OPPORTUNITIES

- Ballard delivered 250 Kw PEM to Cinergy Corporation for demonstration. Cinergy Corporation publicly stated its commitment to 1.4 GW of installed fuel cell capacity by 2009
- IFC announced a PEMFC program for stationary and vehicle applications
- EPRI and American Power Corp. (Analytic Power) will test 3 kW fuel cell systems for residential and commercial
- BPA to demonstrate residen

AUTOMOTIVE FUEL CELL MARKET FORECASTS

Drivers	Market Volume (units)
2004: Daimler-Benz Commitment 2005: Daimler-Benz Commitment 2006: GM (annual production) 2008: Ballard (annual production)	30,000 100,000 40,000 250,000
2003: CARB= 10% CA Market	200,000
10% of 1997 Worldwide Sales= auto/light truck	5,170,000

Publicly Announced Corporate Commitments

PUBLIC VIEWS OF ENERGY PRODUCERS

"There is clearly a limit to fossil fuel…. But what about the growing gap between demographics and fossil fuel supplies? Some will obviously be filled by hydroelectric and nuclear power. Far more important will be the contribution of alternative, renewable energy supplies."
Chris Fay
Chairman and CEO, Shell UK Ltd.

"Embrace the future and recognize the growing demand for a wide array of fuels; or ignore reality and slowly—but surely—be left behind."
Mike R. Bowlin
Chief Executive Officer, ARCO
9th February 1999

"I believe that if we're going to meet the world's needs for energy—including oil and gas, we have to help resolve the risks of climate change. That's why we've set our own target to reduce emissions from our activities by 10 percent over the next decade."
Sir John Browne, Chief Executive Officer, BP Amoco
13th September 1999

HYDROGEN INITIATIVES

- SunLine Transit Agency - renewable hydrogen transportation system
- Houston Advanced Research Center - stationary fuel cell demonstration
- Nevada Test Site/Las Vegas - hydrogen transportation infrastructure
- Chicago Transit Authority - fuel cell bus demonstration
- California Fuel Cell Partnership
- State of Florida

CALIFORNIA FUEL CELL PARTNERSHIP

- California Air Resources Board, California Energy Commission, DaimlerChrysler, Ford, Honda, Toyota, and Volkswagen to test fuel cell vehicles (Plans call for initial testing of 50 cars and 20 buses)
- Manufacturers will validate durability and emission performance in “real-life” driving conditions
- Ballard Power Systems will provide fuel cells for the tests
- Texaco, Shell, and ARCO will provide the hydrogen fuel

DEPARTMENT OF ENERGY
HYDROGEN R&D PROGRAM

HYDROGEN PROGRAM TIMELINE

- 1970 Hydrogen Program initiated following OPEC oil embargo
- 1980's reduced R&D budget focused on advanced production and storage
- 1990 enabling legislation expands DOE role in developing hydrogen energy
  - Matsunaga Hydrogen R&D Act of 1990
  - Clean Air Act Amendements of 1990
- 1992 passage of Energy Policy Act and formation of the Hydrogen Technical Advisory Panel
- 1996 Hydrogen Future Act reauthorized Matsunaga Act to extend funding through 2001
- 1998 DOE Hydrogen Program Strategic Plan published
- 1999 DOE and HTAP report to Congress published

HYDROGEN PROGRAM FUNDING

Year	Appropriations (MM$)
1992	1.40
1993	3.85
1994	10.00
1995	10.00
1996	14.50
1997	15.00
1998	15.80
1999	22.25
2000	25.00
2001	29.00

STRATEGIC APPROACH

- Expand the use of hydrogen in the near term by working with industry to improve efficiency, lower emissions, and lower the cost of hydrogen production
- Work with fuel cell manufacturers to develop hydrogen-based electricity storage and generation systems that will enhance the introduction and production of distributed systems
- Demonstrate safe and cost-effective systems for hydrogen vehicles in urban non-attainment areas, and to provide on-board hydrogen storage systems
- Lower the cost of technologies that produce hydrogen directly from sunlight and water

PROGRAM STRUCTURE

Core R&D — Conducts research and engineering development in the areas of hydrogen production, storage, and utilization. The Program maintains and constantly reviews a diversified R&D portfolio of near-, mid-, and long-term technologies.

Technology Validation — Performs the integration of components and subsystems into test-beds and various subsystems into first-of-a-kind systems and prototypes.

PROGRAM STRUCTURE

Planning and Systems Analysis — Links the long-term vision for hydrogen energy with near-term opportunities through the use of economic and technological simulations, by offering a cost-effective means to identify hydrogen pathways that are capable of meeting societal needs.

Outreach and Education — Educates and informs the private sector on the benefits and technology advances made in hydrogen technologies and facilitates the exchange of technical information to schools and non-scientific audiences.

HYDROGEN PRODUCTION R&D

- Fossil-based
- Biomass-based
- Solar/water-based

HYDROGEN STORAGE R&D

- Pressurized storage
- Chemical storage
- Gas on solid storage

HYDROGEN UTILIZATION R&D

- PEM fuel cells
- Hydrogen sensors
- Reversible fuel cells

TECHNOLOGY VALIDATION

- Renewable Hydrogen Systems
  - Integrated PEMFC-renewable hydrogen storage for remote power and island systems
- Hydrogen Infrastructure
  - Thermo conversion to co-produce hydrogen and electricity
  - Storage
  - Industrial FCV/ AP vehicle
- Remote and Village Power
  - Remote village diesel/PEMFC

REGIONAL ADVANTAGES

- Progressive attitude towards sustainable energy
- Local businesses involved in hydrogen
- Experience with PAFC at wastewater treatment plant
- BPA's residential fuel cell initiative
- Available renewable energy resources

ROUNDTABLE DISCUSSION TOPICS

- Traditional Hydrogen production (fossil fuels, economies of scale) vs. distributed hydrogen production (fossil fuels, fuel options, electrolysis, renewables, economies of manufacture)
- Hydrogen as a transportation fuel – can hydrogen compete? Is on-board hydrogen storage the key problem? For light duty (passenger) vehicles? For heavy duty (fleet) vehicles?
- Will renewables be able to compete with fossil-derived hydrogen? Will incentives be necessary to drive a transition?
- Will fuel cell powerplants compete in transportation markets? Are infrastructure barriers the key? How can they be overcome?
- What is your company's reaction to this marketplace?
- Have you made significant technology or other investments?
- Are you evaluating others?
- What can Federal government best focus on to realize the potential for a Hydrogen marketplace?
- In what areas should DOE play a more significant role? Are there areas where DOE should play a less significant role?

APPENDIX C:
PHASE 1 Educational Forum

Sample Invitational Presentation

What You Can't See, Smell or Taste...

Will Electrify You!

Hydrogen: Chemistry for a Global Energy Solution

Jonathan W. Hurwitch
Laura A. Kervitsky
Matt Rowles
Christina MacLean
Sentech, Inc.

Who Wants to be a Chemist?

4 **Dihydrogen Oxide** ➡ H_2O ➡ **Water**

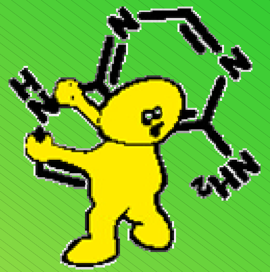
4 **Sodium Chloride** ➡ **NaCl** ➡ **Salt**

4 **Sodium Hypochlorite** ➡ **NaOCl** ➡ **Bleach**

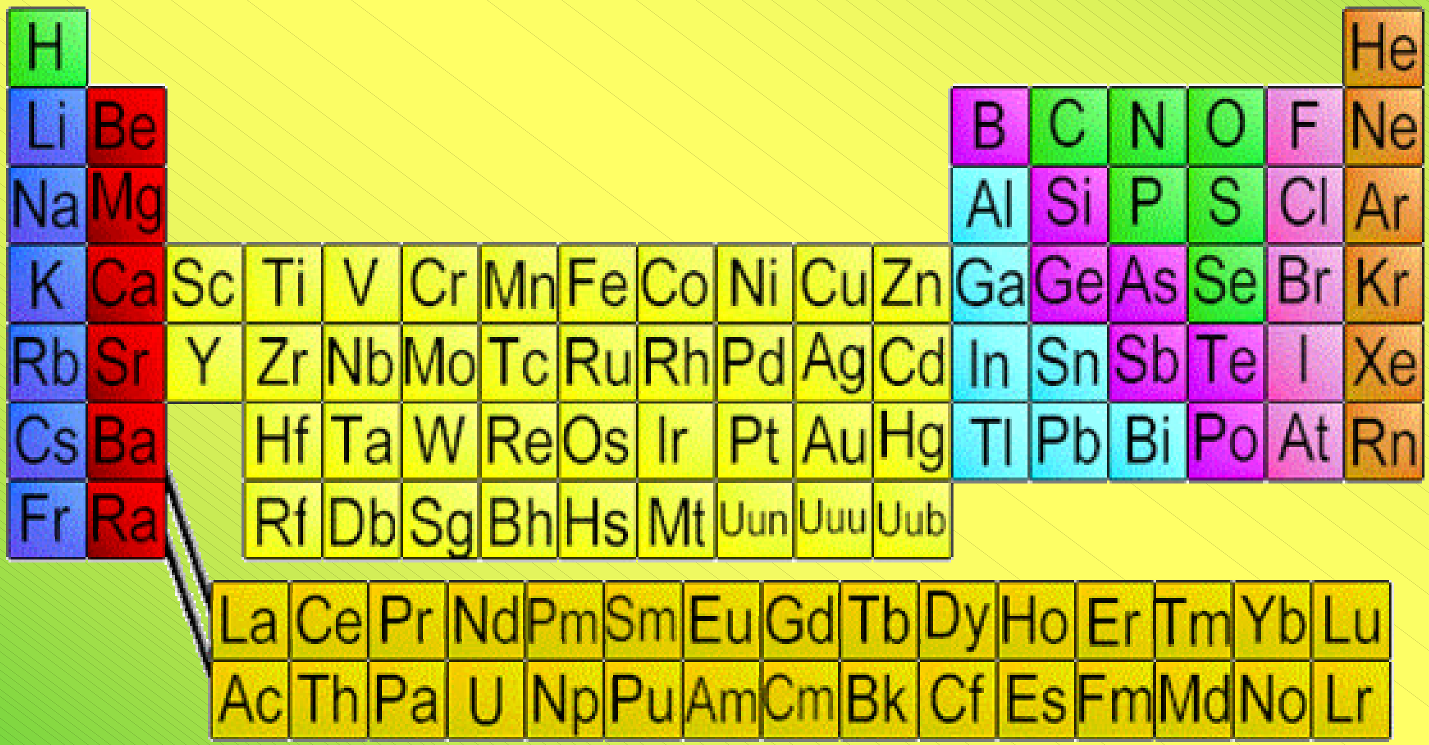
4 **Ammonium Hydroxide** ➡ NH_4OH ➡ **Ammonia**

4 **Polystyrene** ➡ C_8H_8 ➡ **Styrofoam™**

Who is #1?

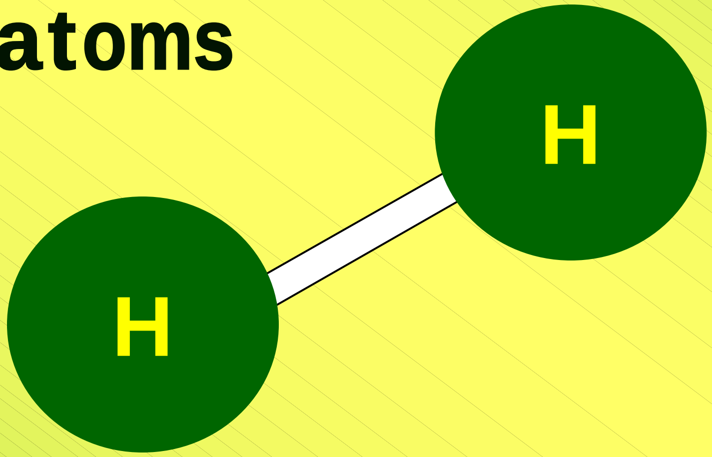


Atomic Number: 1
Atomic Symbol: H
Atomic Weight: 1.0079



The Hydrogen Facts

4 **A hydrogen gas molecule has two hydrogen atoms**



4 **Hydrogen is lighter than air**

4 **Hydrogen boils at 20.4 Kelvin (-253C)**

Hydrogen is Everywhere and Nowhere

4 **Hydrogen is a component of almost everything around us**

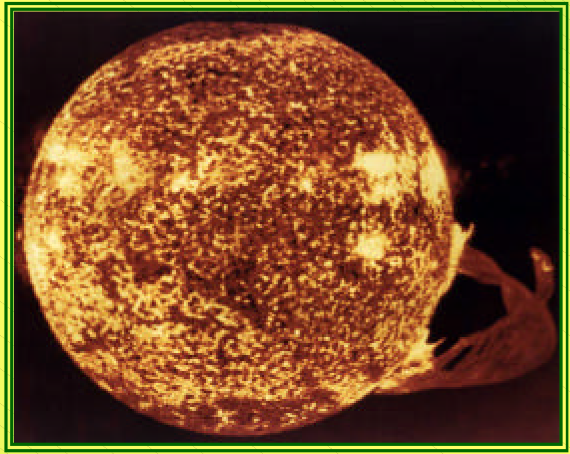
4 **But, hydrogen doesn’t exist alone in nature**

Hydrogen in Nature

4 **Hydrogen gas makes up 90% of all atoms in the universe**

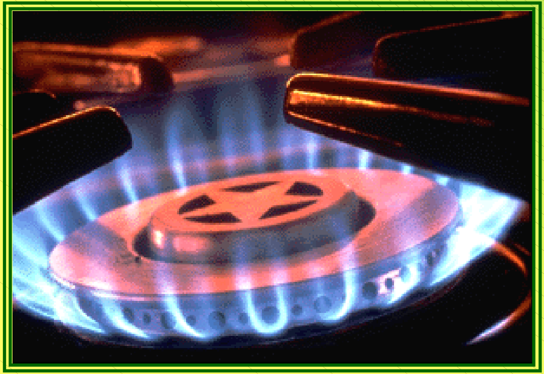
4 **Our sun is 92.1% hydrogen atoms and 7.8% helium**

4 **Every second, the sun converts 700 million tons of hydrogen to 695 million tons of helium**



Combustion: Combining with Oxygen

4 **Fossil fuels**



4 **Hydrogen and oxygen**

Let’s Make Hydrogen

4 **Extract hydrogen from fossil fuels**

“Steam Reformation”

$$CH_4 + 2H_20 \rightarrow 4H_2 + CO_2$$

4 **Separate hydrogen from water**

“Water Electrolysis”

$$2H_2O + 2e^- \rightarrow 2H_2 + O_2$$

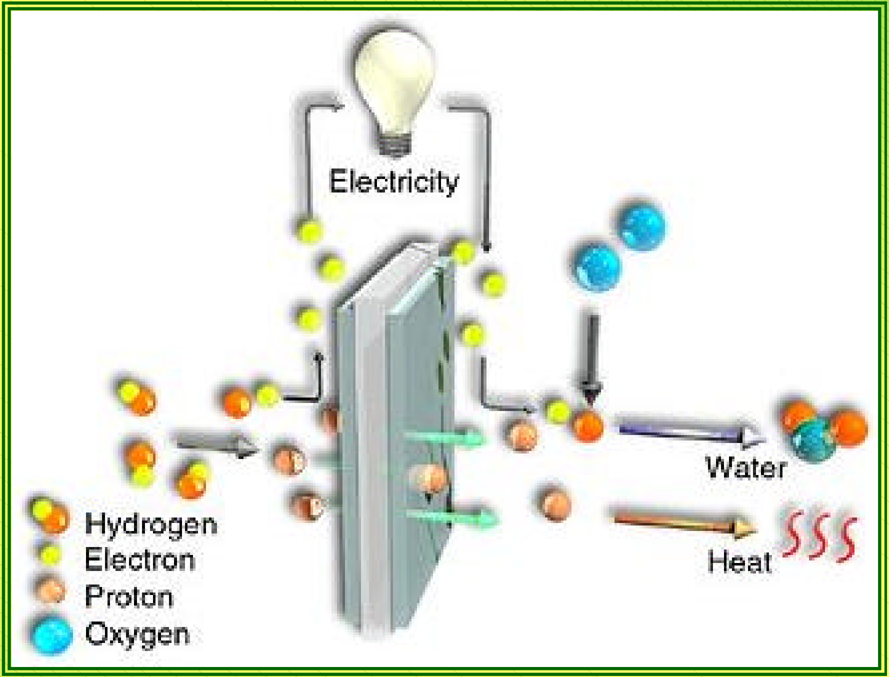
Using Hydrogen

- **Space shuttle uses hydrogen as fuel for launch**
- **And, to power fuel cells which provide on-board electricity**

Electricity from Hydrogen

4 **A fuel cell is the reverse of electrolysis**

4 **Hydrogen fuel combined with oxygen makes water and electricity**



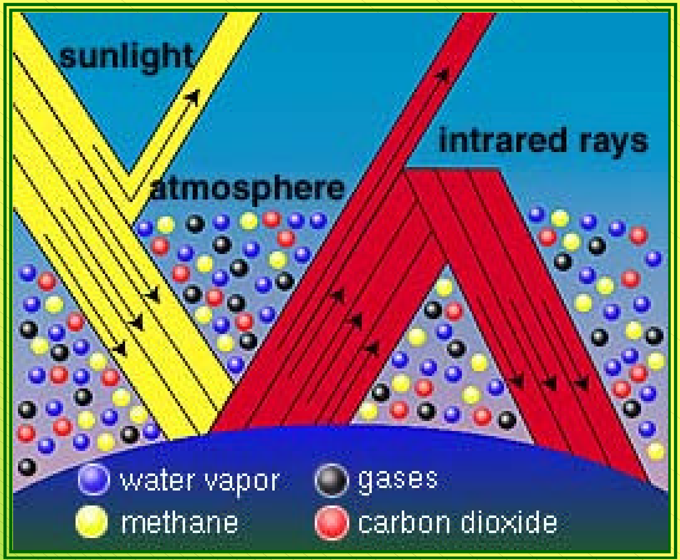
Electricity Today

- **Today's power plants typically use:**
  - **coal**
  - **fuel oil**
  - **natural gas**
  - **nuclear**

Where Does Your Electricity Come From?

4 **Coal**	**51%**
4 **Oil**	**3%**
4 **Natural Gas**	**16%**
4 **Nuclear**	**20%**
4 **Hydro**	**8%**
4 **Renewable**	**2%**

Environmental Consequences



Solar Hydrogen

4 **Today we make electricity from solar cells**

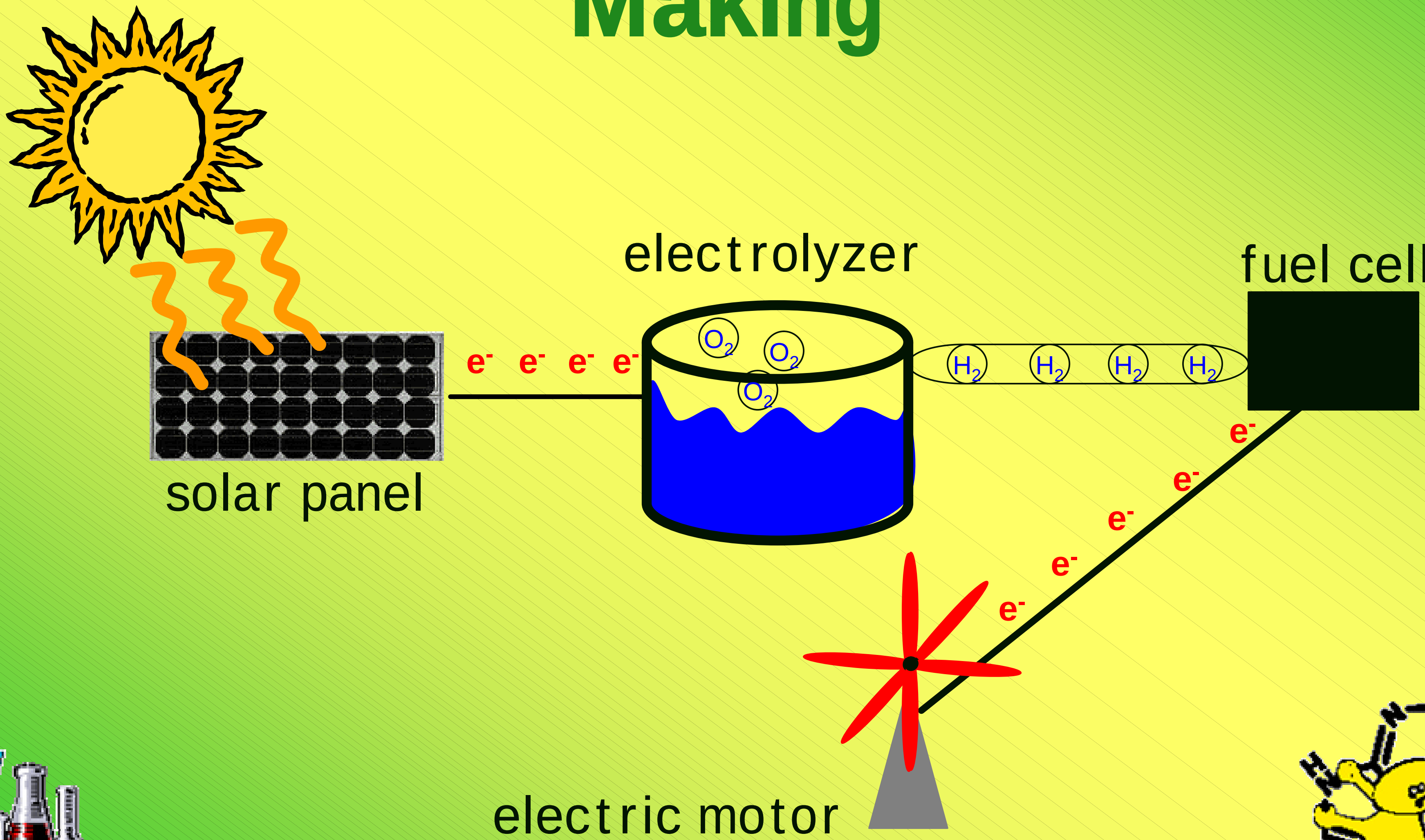
4 **But, there are two major problems with the wide-spread use of solar energy:**

   ™ **cost**

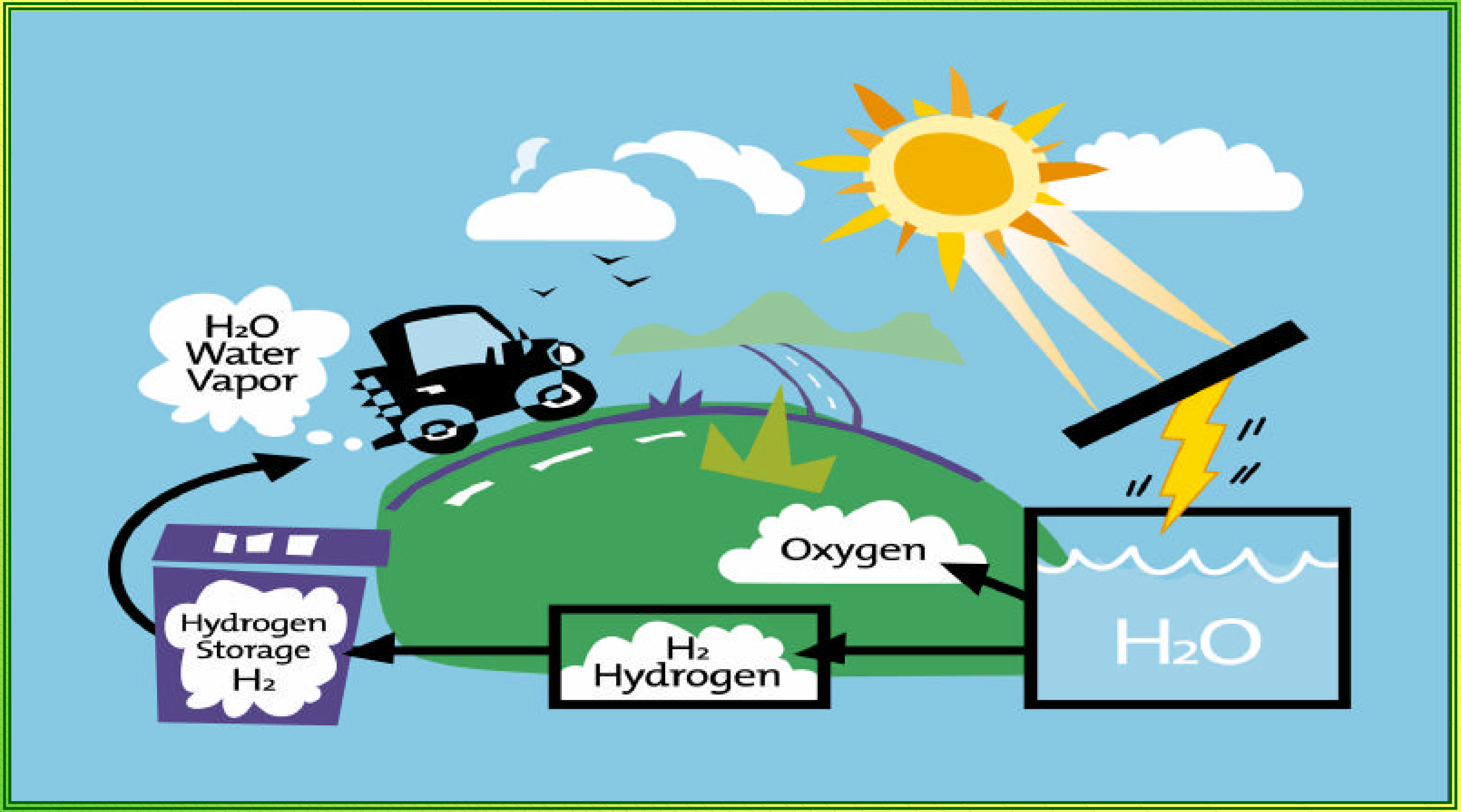
   ™ **intermittent sunlight**

4 **Hydrogen can be used to store solar energy**

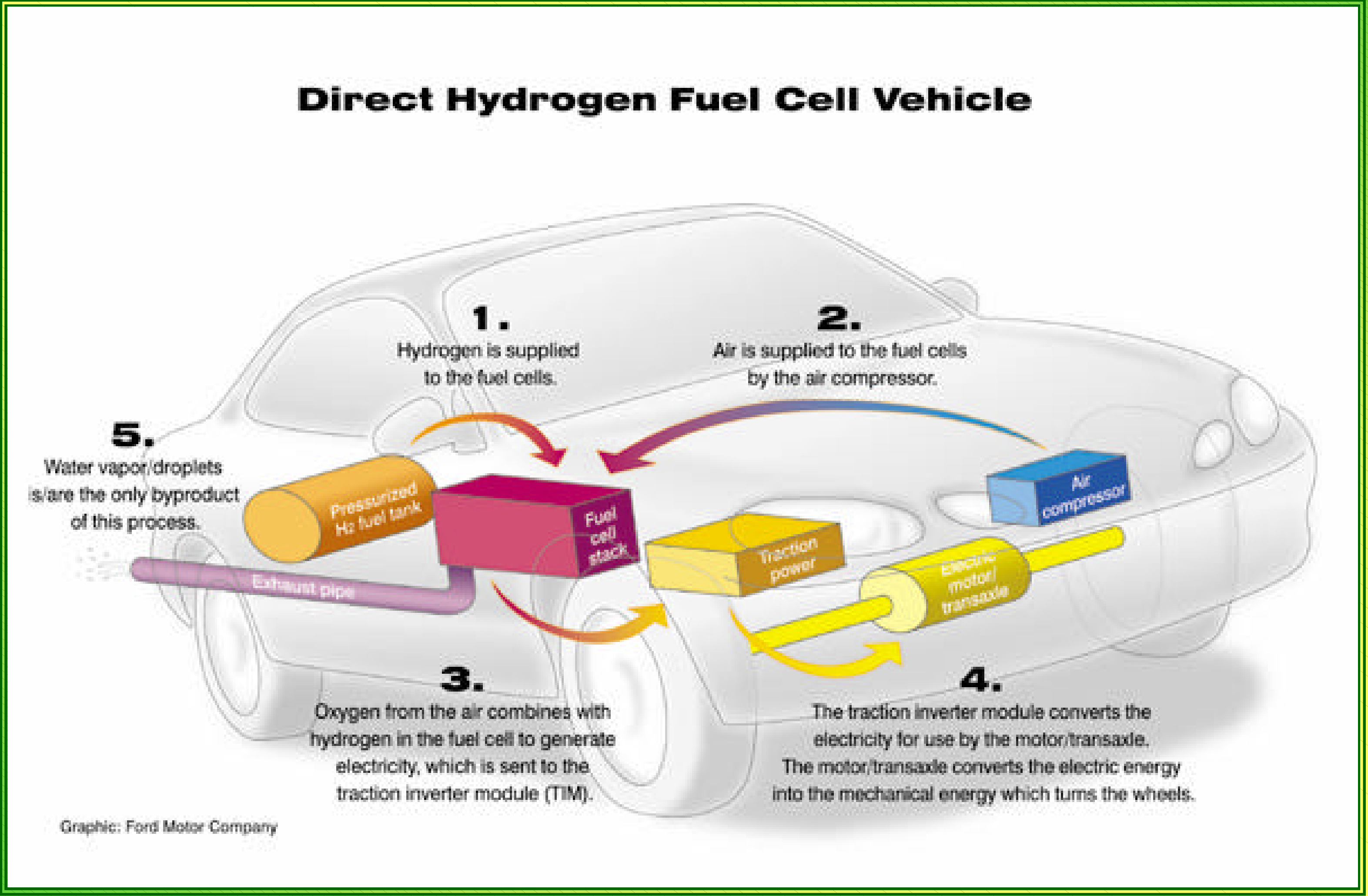
Solar Hydrogen in the Making



Driving on Hydrogen



Hydrogen Vehicles



Your First Car?

Mazda FCEV

Honda FCX

GM Precept

Summary

4 **Hydrogen is an invisible gas**

4 **Hydrogen burns cleanly with oxygen to produce energy and water**

4 **Hydrogen is abundant in nature but “free” hydrogen must be made**

4 **Hydrogen can be made from water via electrolysis**

4 **Electricity can be made from hydrogen and oxygen via fuel cells**

Certificate of Excellence

is hereby granted to:

Charles Hart Middle School

for outstanding participation in

The 5th Annual NHA Secondary School Invitational

Granted: March 7, 2001

Neil P. Rossmeissl
Hydrogen Program Manager
U.S. Department of Energy

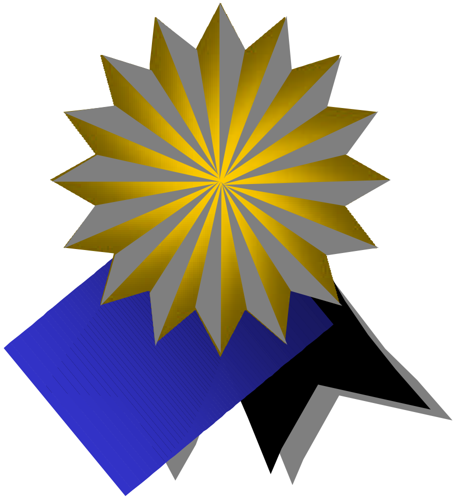
[Company Name]

Certificate of Completion

is hereby granted to:

[name here]

to certify that they have completed to satisfaction



[Course Name]

Granted: March 24, 2006

{name, title}

APPENDIX D:
PHASE 2 EDUCATIONAL FORUM

Training Modules

Hydrogen Training and Certification Course

Module VII

Emergency Response Scenarios

Emergency Response Scenarios

Emergency response scenarios are designed to prepare and practice for hazardous situations that may arise from natural and manmade events and to mitigate threats to life and property.

Hazard Response

"Hazardous materials incident" or "hazardous materials emergency" means an uncontrolled release or threatened release of a hazardous substance requiring outside assistance by a local fire department or hazmat team to contain and control.

Handling Hazardous Materials

The U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) sets standards for handling hazardous materials and responding to hazardous material releases in the workplace (29 CFR 1910). This applies to systems containing at least 10,000 pounds or 16,900 gallons of hydrogen.

Emergency Response Plan

- Elements of an emergency response plan:
  - Pre-emergency planning and coordination with outside parties
  - Personnel roles, lines of authority, training, and communication
  - Emergency recognition and prevention.
  - Safe distances and places of refuge

Emergency Response Plan

- Elements of an emergency response plan:
  - Site security and control
  - Evacuation routes and procedures
  - Decontamination procedures
  - Emergency medical treatment and first aid
  - Emergency alerting and response procedures

Emergency Plan Implementation

- Preparation is key:
  - Understand site topography, layout, and prevailing weather conditions
  - Know reporting procedures to local, state, and federal governmental agencies
  - Include emergency response plan in a separate section of the Site Safety and Health Plan
  - Install an employee alarm system to notify employees of an emergency situation, to stop work activities if necessary, to lower background noise in order to speed communication, and to begin emergency procedures

Emergency Plan Implementation

- Preparation is key:
  - Coordinate and integrate with the disaster, fire and/or emergency response plans of local, state, and federal agencies
  - Rehearse emergency response as part of overall training program for site operations
  - Periodically review and, as necessary, amend to keep it current with new or changing site conditions or information
  - Based upon the information available at time of an emergency, evaluate incidents and site response capabilities and proceed with the appropriate steps to implement the site emergency response plan

Emergency Responder Training

"Training for emergency responders shall be completed before they are called upon to perform in real emergencies. Such training shall include the elements of the emergency response plan, standard operating procedures the employer has established for the job, the personal protective equipment to be worn and procedures for handling emergency incidents."

29 CFR 1910 Occupational Safety and Health Standards

Hydrogen Hazards

- Chemical Hazards
  - Asphyxiation (condition caused by insufficient oxygen)
- Physical Hazards
  - Pressure (sound, shrapnel, pressurized stream)
  - Embrittlement (condition of low ductility and cracking resulting from the occlusion of hydrogen in metals, especially steel)
  - Cryogenic burns (resulting from contact with liquid hydrogen)
- Combustion Hazards
  - Detonation (a violent release of confined energy)
  - Deflagration (combustion that propagates through a gas or along the surface of an explosive at a rapid rate driven by the transfer of heat)

Department of Transportation

The U.S. DOT publishes the Emergency Response Guidebook (ERG). The ERG addresses all hazardous materials regulated by the DOT and presents information on the potential hazards, public safety, and emergency response procedures. Section 115 applies to gaseous and liquid hydrogen.

GUIDE 115 — GASES - FLAMMABLE (INCLUDING REFRIGERATED LIQUIDS)

ERG2004

POTENTIAL HAZARDS

FIRE OR EXPLOSION

- **EXTREMELY FLAMMABLE.**
- Will be easily ignited by heat, sparks or flames.
- Will form explosive mixtures with air.
- Vapors from liquefied gas are initially heavier than air and spread along ground.

  CAUTION: Hydrogen (UN1049), Deuterium (UN1957) and Methane (UN1971) are lighter than air and will rise. Hydrogen and Deuterium fires are difficult to detect since they burn with an invisible flame. Use an alternate method of detection (thermal camera, broom handle, etc.)
- Vapors may travel to source of ignition and flash back.
- Cylinders exposed to fire may vent and release flammable gas through pressure relief devices.
- Containers may explode when heated.
- Ruptured cylinders may rocket.

HEALTH

- Vapors may cause dizziness or asphyxiation without warning.
- Some may be irritating if inhaled at high concentrations.
- Contact with gas or liquefied gas may cause burns, severe injury and/or frostbite.
- Fire may produce irritating and/or toxic gases.

PUBLIC SAFETY

- **CALL Emergency Response Telephone Number on Shipping Paper first. If Shipping Paper not available or no answer, refer to appropriate telephone number listed on the inside back cover.**
- As an immediate precautionary measure, isolate spill or leak area for at least 100 meters (330 feet) in all directions.
- Keep unauthorized personnel away.
- Stay upwind.
- Many gases are heavier than air and will spread along ground and collect in low or confined areas (sewers, basements, tanks).
- Keep out of low areas.

PROTECTIVE CLOTHING

- Wear positive pressure self-contained breathing apparatus (SCBA).
- Structural firefighters' protective clothing will only provide limited protection.
- Always wear thermal protective clothing when handling refrigerated/cryogenic liquids.

EVACUATION

Large Spill

- Consider initial downwind evacuation for at least 800 meters (1/2 mile).

Fire

- If tank, rail car or tank truck is involved in a fire, ISOLATE for 1600 meters (1 mile) in all directions; also, consider initial evacuation for 1600 meters (1 mile) in all directions.

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ERG2004

Gases - Flammable (Including Refrigerated Liquids)

GUID 115

EMERGENCY RESPONSE

FIRE

- **DO NOT EXTINGUISH A LEAKING GAS FIRE UNLESS LEAK CAN BE STOPPED.**

CAUTION: Hydrogen (UN1049) and Deuterium (UN1957) burn with an invisible flame.

Small Fires

- Dry chemical or CO_2.

Large Fires

- Water spray or fog.
- Move containers from fire area if you can do it without risk.

Fire involving Tanks

- Fight fire from maximum distance or use unmanned hose holders or monitor nozzles.
- Cool containers with flooding quantities of water until well after fire is out.
- Do not direct water at source of leak or safety devices; icing may occur.
- Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank.
- ALWAYS stay away from tanks engulfed in fire.
- For massive fire, use unmanned hose holders or monitor nozzles; if this is impossible, withdraw from area and let fire burn.

SPILL OR LEAK

- ELIMINATE all ignition sources (no smoking, flares, sparks or flames in immediate area).
- All equipment used when handling the product must be grounded.
- Do not touch or walk through spilled material.
- Stop leak if you can do it without risk.
- If possible, turn leaking containers so that gas escapes rather than liquid.
- Use water spray to reduce vapors or divert vapor cloud drift. Avoid allowing water runoff to contact spilled material.
- Do not direct water at spill or source of leak.
- Prevent spreading of vapors through sewers, ventilation systems and confined areas.
- Isolate area until gas has dispersed.

CAUTION: When in contact with refrigerated/cryogenic liquids, many materials become brittle and are likely to break without warning.

FIRST AID

- Move victim to fresh air. • Call 911 or emergency medical service.
- Give artificial respiration if victim is not breathing.
- Administer oxygen if breathing is difficult.
- Remove and isolate contaminated clothing and shoes.
- Clothing frozen to the skin should be thawed before being removed.
- In case of contact with liquefied gas, thaw frosted parts with lukewarm water.
- In case of burns, immediately cool affected skin for as long as possible with cold water. Do not remove clothing if adhering to skin. • Keep victim warm and quiet.
- Ensure that medical personnel are aware of the material(s) involved and take precautions to protect themselves.

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Gaseous Hydrogen Leak

Gaseous hydrogen leak:

1. Evacuate area of nonessential personnel.
2. Shut off the hydrogen source immediately if safe to do so and vent all hydrogen to a safe outside location.
3. Eliminate any ignition sources in the area of the leak.
4. Increase indoor ventilation with emergency explosion-proof exhaust fans, if possible.
5. Implement emergency plan and make required emergency contacts.

Small Hydrogen Fire

Hydrogen fire:

1. Evacuate area of nonessential personnel.
2. Shut off the hydrogen source if safe to do so.
3. Let the fire burn itself out. (If the flame is snuffed out, it may reignite and cause greater damage.)
4. Use water spray to thermally protect people and equipment if the fire is hot enough to warrant it. A venting hydrogen flame cannot normally be extinguished with water.
5. Implement emergency plan (which should include calling the fire department) and make required emergency contacts.

Liquid Hydrogen Spill

Liquid hydrogen spill:

1. will results in a ground-level flammable cloud for a brief time. As the liquid vaporizes and hydrogen gas mixes with air it disperses to a nonflammable concentration, warms up and becomes buoyant.
2. Do not contain a liquid hydrogen spill. Maintain ventilation, stay away from any surface in contact with cryogenic hydrogen.
3. Any clothing sprayed or soaked with liquid hydrogen should be allowed to air out.

Hydrogen Training and Certification Course

Module V

Hydrogen Dispensing and Transfer

Supply Options

- Hydrogen can be produced on-site or off-site depending on the demand at the site.
- Compressed hydrogen delivery is often chosen when the fuel dispensed per day is relatively low while liquid hydrogen delivery is chosen for sites with high demand.
- Different delivery and production modes requires a significantly different fueling station design and a different set of safety procedures.

Supply Options – Off-Site

- Hydrogen produced off-site is delivered to the sites by trucks, tube-trailers, or pipelines in liquid or gaseous form.
- Gaseous hydrogen is compressed and stored in specially designed containers capable of withstanding pressures up to 5000 psi.
- Liquid hydrogen is stored in special cryogenic storage equipments until dispensed.
- Liquid and gaseous hydrogen require different operating, handling and safety procedures.

Supply Options – On-Site

- Hydrogen can also be produced on-site by electrolysis or reforming.
- Electrolysis as well as all three reforming technologies: steam reforming (SR), partial oxidation (POX), and autothermal reforming (ATR) require additional safety considerations and procedures due to the use of heat/electricity.
- Hydrogen produced on-site may have to be liquefied and stored under cryogenic conditions.

Site Requirements

- Requirements siting should include a review of zoning requirements, review of method for transport of hydrogen to the site, and review of method for transfer of hydrogen from a transport vehicle or pipeline to the site storage system.
- There also must be sufficient room at the site for a truck or other vehicle to unload.
- Buildings at the site must be positioned so that separation distance requirements are met.

Transfer

- The delivered hydrogen is stored in appropriate storage containers at the site until it is dispensed to fuel cell vehicles.
- Appropriate precautionary steps should be taken to ensure safe operation of high pressure compressors and equipments under cryogenic conditions.
- Personnel conducting the transfer operations should be authorized and highly trained in safety procedures.

Transfer Contd.

- Hydrogen is transferred to pressure vessels at the site via specially designed compressors.
- Transfer procedures differ for gaseous and liquid Hydrogen. Appropriate pre-transfer procedures (e.g. purging), depending on the properties of Hydrogen, should be implemented.
- A checklist for safe transfer operation should be developed (or obtained from the site operator), maintained and vigorously followed.

Transfer Contd.

- PRDs and other safety devices should be periodically examined externally for corrosion, damage, mechanical defects, and leakage.
- The transfer equipments such as pressure relief devices (PRDs), tank fill-pressure flow shutoff devices, breakaway protection devices, etc. should be operated as per specified instructions.
- Personnel conducting the transfer operation should be aware of provisions for emergency equipment access (e.g., fire department equipments) provided at the site.

Communications Protocol

- The fuel tank should not be overheated or over pressured beyond its safe limits during fill ups. This can be achieved by either of the following:
  - Opting for 'fast-fill' i.e. fill under 5 minutes. This option requires connecting a separate communication cable between the vehicle and the dispensing unit which transfers information about fuel tank, its manufacturer and manufacturer set specific conditions required to begin fueling.
  - Opting for a 'slow-fill' i.e. fill under 15 minutes which does not require the user of the communication cable.

Dispensing

- To ensure safe refueling, the vehicle should be grounded, pass a series of safety verifications, and have all the electrical systems turned off.
- In the case of a fast-fill, the communication cable should be properly connected to the vehicle and the connection established.
- Before refueling begins, the dispensing nozzle should be properly connected to the vehicle receptacle.

Dispensing Contd.

- First generation hydrogen dispensers have evolved from equipment originally designed for dispensing CNG and therefore should follow similar safety requirements.
- A high pressure dispensing nozzles connected to a low pressure vehicle receptacles can result in hydrogen leaks and related accidents.
- Dispensers for liquid and compressed hydrogen fueled vehicles are different. Approved operating instructions for the use of the dispensers must be followed carefully while dispensing hydrogen.

Dispensing Contd.

- All dispensing devices and communication links should be inspected at regular intervals, not only for wear and tear but also for calibration errors and other inaccuracies.
- Vehicle fueling hoses should be examined visually at such intervals as are necessary to ensure that they are safe for use.
- All dispensing and transferring operations should be immediately turned off and equipment shut down, manually if not automatically, at the first sign of an alarm.

Facility Requirements

- Clear regulatory signs such as “No Smoking”, “Only non-sparking tools permitted”, etc. should be displayed at the site.
- Regular inspection, replacement or servicing of equipment at the site should be conducted as per manufacturer’s recommendations.
- All personnel must be trained in safety and emergency response procedures, troubleshooting, and evacuation plans.

Facility Requirements – Contd.

- An emergency response plan should be developed and implemented in the event of an accident. The plan should be updated at regular intervals, if necessary.
- Inputs from staff should be regularly obtained for developing and modifying operating and safety procedures for the hydrogen station.
- Operational data such as system pressure readings, flow rate, etc. should be recorded, maintained and monitored.

Public Education

- Clear and concise instructions for operating the dispensing unit should be displayed on the dispensing unit.
- Instructions for emergency procedures, in the event of an accident, should be made easily accessible to the user of the dispensing unit.
- Public should be informed through various mediums (e.g. demonstration for first time users) on how to safely operate the dispensing unit.

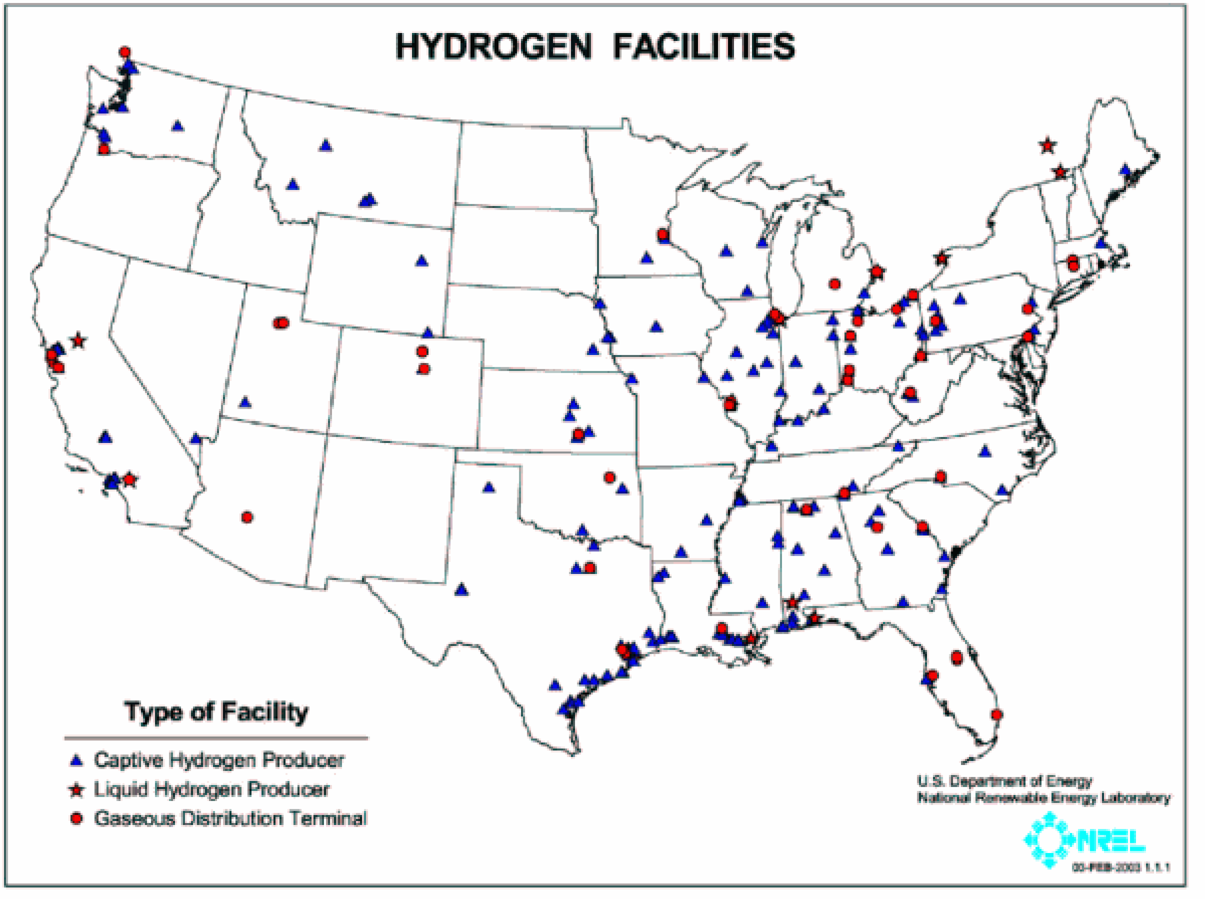
Hydrogen Training and Certification Course

Module IV

Hydrogen Storage & Piping

Location of Hydrogen Production Facilities

Hydrogen is produced at a number of facilities around the country and transported to consumers primarily by truck and either immediately used or stored on site. Pipelines exist in the gulf region to supply the petroleum refining industry, and in Los Angeles.



Hydrogen Storage

- Perhaps the most important and most challenging component of the hydrogen energy system.
- Key challenges:
  - Weight and volume
  - Efficiency
  - Durability
  - Refueling time
  - Cost
  - Codes and standards
  - Life-cycle and efficiency analysis

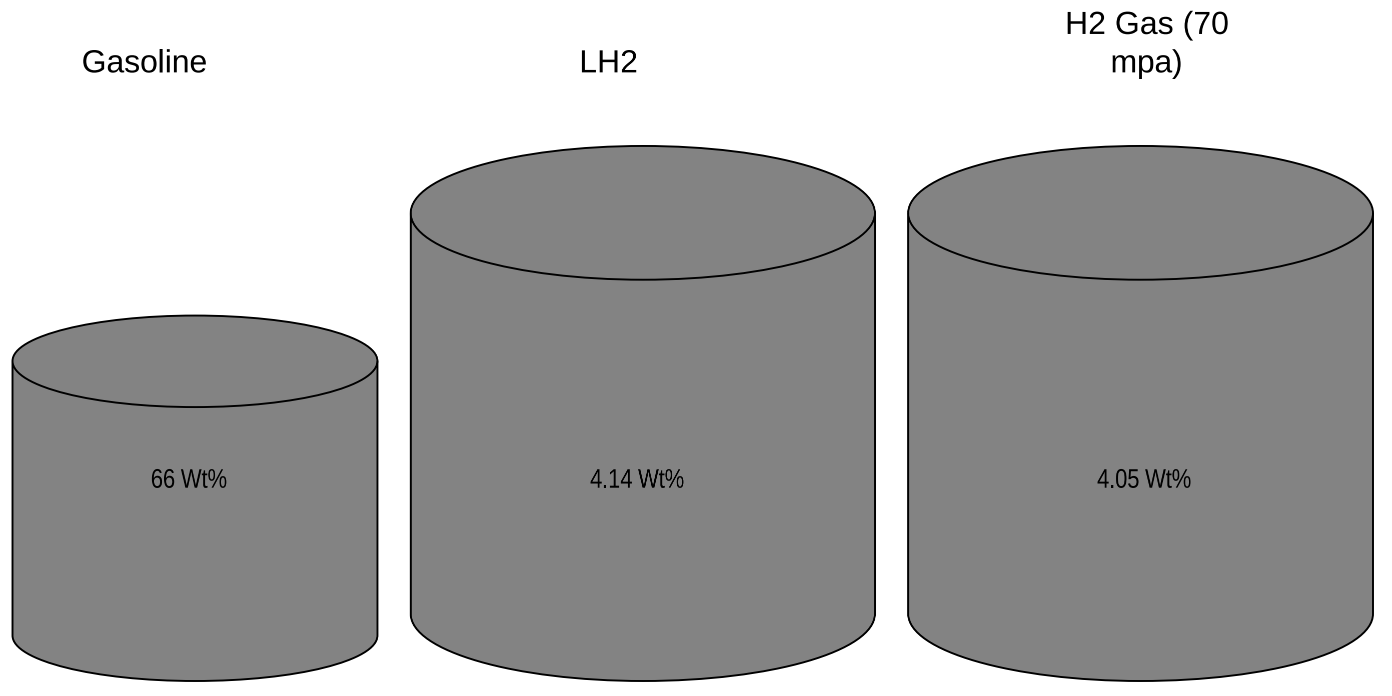
Storage Methods

- Primary hydrogen storage methods:
  - Compressed gas
  - Cryogenic liquid
  - Chemical carriers
  - Solid State
- Selecting the storage method depends on:
  - Available space
  - Duration of storage
  - Volume to be stored
  - Weight of storage system

Storage Terminology

- *Volumetric energy density*: The total amount of energy that can be stored in a given volume
- *Gravimetric energy density*: The ratio of the amount of energy stored in a device to the weight of the device (often expressed as a percent)

Fuel Comparison

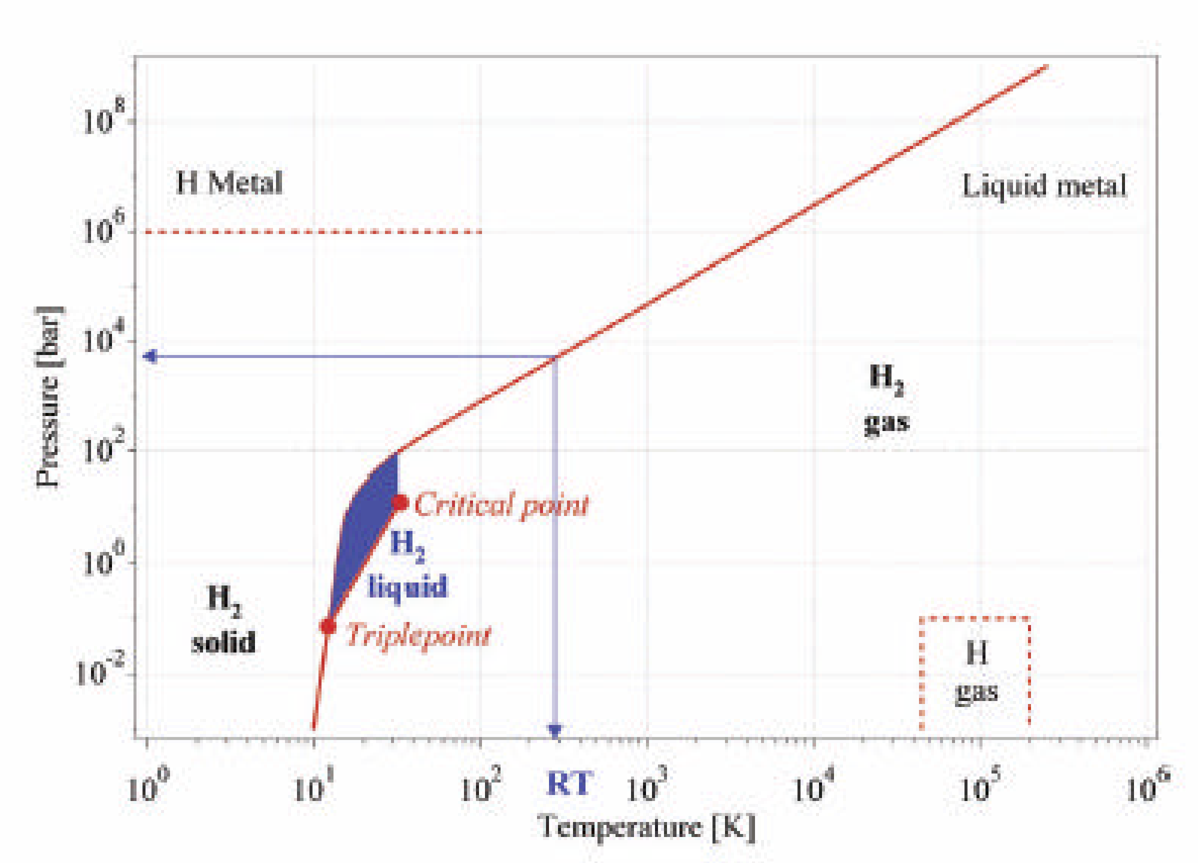


Calculation of the gravimetric energy density of fuel needed to drive 250 miles. Expressed as a percentage of the weight of fuel to the weight of fuel storage system

Increasing Energy Density of Stored Hydrogen

- To increase the energy density of stored hydrogen, the gas must be mechanically compressed or converted to a liquid through mechanical compression combined with extremely low temperatures.
- The hydrogen phase diagram illustrates the extremes of pressure and temperature required to achieve higher energy density.

Hydrogen Phase Diagram



Liquid hydrogen only exists between the solid line and the line from the triple point at 21.2 K and the critical point at 32 K.

Gaseous Storage

- Compressed hydrogen
  - Steel cylinders
    - 5000 psi
    - Gravimetric energy density: 0.5 – 1% hydrogen by weight
  - Composite tanks
    - 10,000 psi
    - Gravimetric energy density: 7% hydrogen by weight

Pressure vessels of the future will be constructed of three layers: an inner polymer liner over-wrapped with a carbon-fiber composite (the stress-bearing component) and an outer layer of an aramid-fiber capable of withstanding mechanical and corrosive damage.

Steel Tanks

- Advantages:
  - Available technology
  - Commonly used
  - Inexpensive
- Disadvantages:
  - Subject to embrittlement
  - Produces projectiles if ruptured or sharp stream if punctured
  - Bulky
  - Low storage volume by weight

Composite Tanks

- Advantages:
  - Conformable to fit in small spaces
  - Absorb impact and powder rather than rupture
- Disadvantages:
  - Expensive
  - Low storage volume by weight

Liquid Hydrogen Storage

- Technology Description
  - Hydrogen is liquefied at 20.268 K (–253 °C or -423 °F) through a process of pressurization and active cooling
  - LH2 storage tanks are designed to protect against:
    - *Thermal Radiation* – with multi layer insulation (layers of metallic foil with glass wool) to reduce external thermal radiation.
    - *Thermal Convection* - the insulated inner vessel mounted within an outer vessel with a vacuum between to minimize thermal convection.
    - *Thermal Conduction* – special design and materials used to minimize thermal conduction.

Liquid Hydrogen Storage

- Advantages
  - Higher volumetric energy density
- Disadvantages
  - Energy required for liquefaction (typically 30% of the heating value of stored hydrogen)
  - Boil-off
  - Low gravimetric energy density
  - Cost

Chemical Storage

- Technology Description
  - Hydrogen containing compounds undergo chemical reaction to evolve hydrogen
    - Hydrolysis
    - Hydrogenation / dehydrogenation
  - Chemical candidates: methanol, ammonia
  - Reaction driven by heat, catalysts, pH change

Chemical Storage

- Advantages
  – Avoid the need to store hydrogen
- Disadvantages
  – Regeneration of chemical carrier
  – Managing the hydrogen evolving reaction
  – Hazards associated with chemical carrier

Solid State

- Technology description
  - Storage container packed with material that physically attracts hydrogen molecules
    - Hydrogen adsorption on high-surface carbon materials by van der Waals forces
    - Hydrogen absorbed in metal alloys by hydrogen bonding

Solid State

- Advantages
  - Bound hydrogen is more stable and less hazardous
- Disadvantages
  - Low gravimetric energy density for metal hydrides
  - Slow kinetics of absorption and release
  - Selectivity of material to hydrogen
  - Reversibility

Storage Applications

- Mobile Storage
  - On-board storage (vehicular)
  - Transportation tanker storage (truck, barge, train)
- Stationary Storage
  - Bulk storage
  - Point of use storage

Mobile Storage Technology Candidates

- Pressurized gas
- Liquid hydrogen
- Chemical carrier
- Solid state

Stationary Storage Technology Candidates

- Pressurized gas

Components of Hydrogen Storage Systems

- In addition to the storage container, several other components are needed for safe and efficient storage and dispensing of hydrogen:
  - Connectors
  - Piping
  - Vents
  - Controllers
  - Sensors

Gaseous Hydrogen Transport via Pipeline

- Gaseous hydrogen is transported via dedicated pipelines in and around petroleum refineries
- There are approximately 900 miles of dedicated hydrogen pipeline in the U.S.
  - Pipelines offer the safest and most efficient transport of hydrogen to large industrial users

- There needs to be something that comes here….not sure what

Hydrogen Pipeline Safety

- Pipeline safety measures implemented near areas of “high consequence” include
  - heavier pipeline wall thickness
  - excess flow shut-off valves – Emergency Flow Restricting Device (EFRD)
  - isolation valves
  - redundant pressure safety relief valves
  - frequent in-field inspections (by ground and air) and repair

Pipeline Safety Regulations

- Hydrogen pipeline transport (outside of production facilities) is regulated by the Department of Transportation Office of Pipeline and Hazardous Materials Safety Administration (PHMSA)
  - PHMSA also develops safety and inspection criteria for the interface between fuel delivery and bulk storage systems
- The regulations governing pipeline distribution of hydrogen are found in 49 CFR Parts 171-180 and 190-199
- States and municipalities also may promulgate regulations

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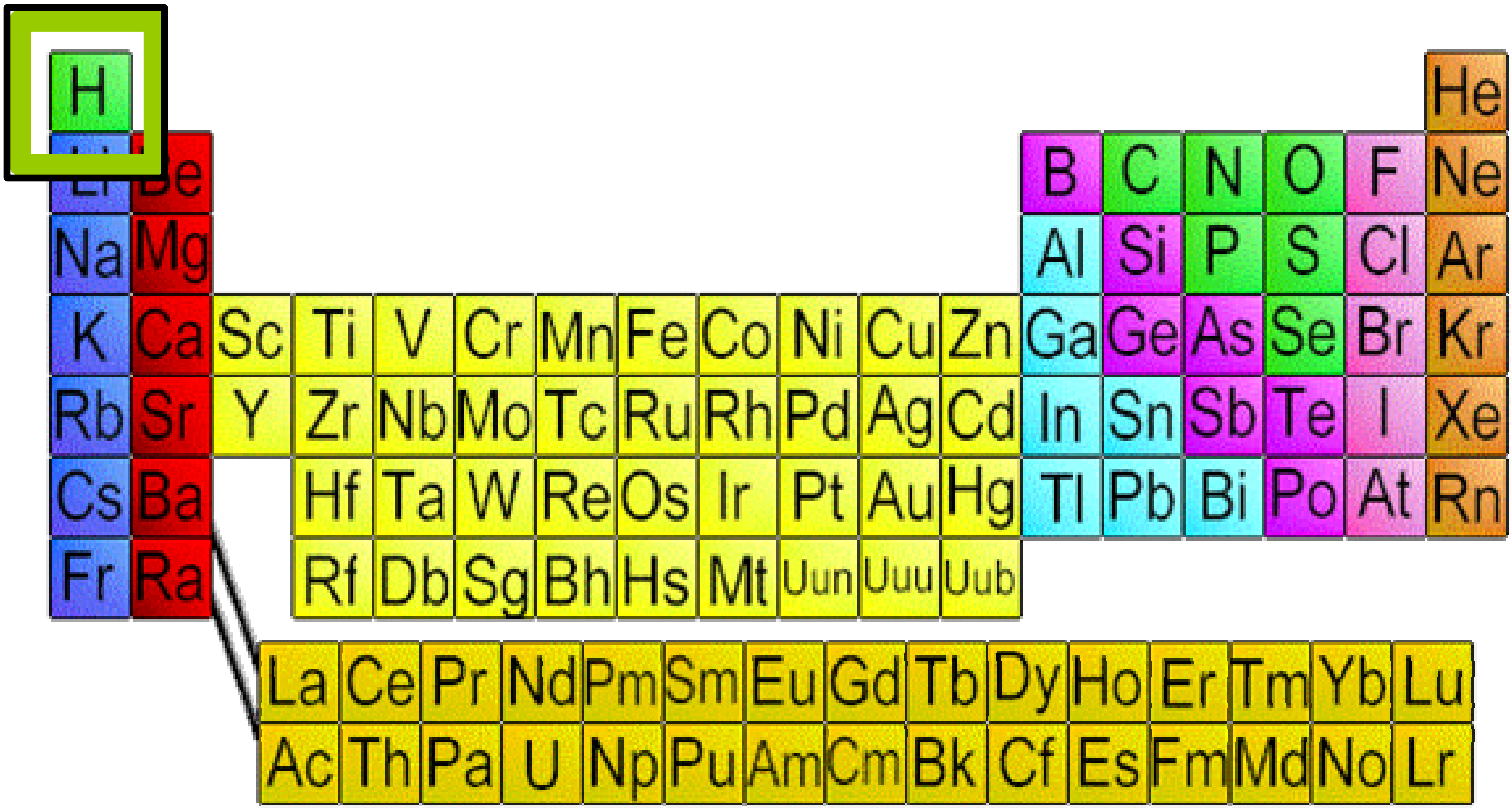
Module II

Hydrogen Properties & Applications

Hydrogen, What's your experience?



Hydrogen, What's your experience?

- Hydrogen's physical and chemical properties have made it a valuable industrial commodity for over 50 years;
- In addition to its use as an industrial gas, liquid hydrogen is also used as a rocket propellant;
- Hydrogen is used in the following industries:
  - Petroleum refining
  - Chemical manufacturing (various chemicals including ammonia)
  - Steel and Specialty Metal Production and processing
  - Food processing (production of edible fats and oils
  - Semi-conductor Manufacturing
  - Electronics Industry
  - Glass Manufacturing
  - Synthetic Diamond Manufacturing
  - Electric Generation (Heat transfer fluid)

Hydrogen, What's your perception?

The perception of "hydrogen" has been incorrectly shaped by three well-publicized events and their vividly haunting images

- 1937 Hindenburg Airship disaster
- 1952 Development and testing of the hydrogen bomb
- 1986 Space Shuttle Challenger accident.

What is Hydrogen?

- Under most conditions, hydrogen is a colorless, odorless, tasteless, and nontoxic gas.
- Hydrogen is very flammable and its physical properties and characteristics make it a very capable fuel and energy carrier.
- Hydrogen has numerous advantages over other fuels in terms of safety. In considering Hydrogen as an energy carrier and fuel, it is important to compare hydrogen to other fuels.
- Hydrogen is the lightest of all the elements on the Periodic Table. As such, it is very buoyant and highly diffusive in the surrounding air, a leak will have no negative environmental impact.
- It has a very low density per unit volume that is approximately 14 times less than air.
- Hydrogen undergoes phase change from gaseous to liquid state at extremely cold temperatures -423°F (20.26°K or -252.89°C).

Hydrogen Safety Considerations

The primary safety considerations associated with hydrogen include:

- **Fire** – Fire requires three ingredients: fuel, an oxidizer (i.e., Oxygen or other substance capable of supporting combustion), and a source of ignition. Hydrogen can be easily ignited in air by heat, open flames, electrical sparks, and static electricity.
- **Explosion** – A fire becomes an explosion if the combustion is sufficiently rapid to cause pressure waves. Hydrogen has the highest energy content per unit mass. Its presence, in concentrations of about 4-74%, can result in ignition. Explosions often result when hydrogen is ignited in enclosed spaces.
- **Asphyxiation** – Hydrogen leaked into enclosed spaces can dilute the concentration of oxygen in air below levels necessary to support life.
- **Tissue Damage** – Liquid hydrogen (LH_2) is extremely cold, –423^{o}F. Contact with the LH_2 or its cold vapors can cause extensive tissue damage.

Hydrogen Safety Considerations

The secondary safety considerations associated with hydrogen include:

- **Embrittlement**
  - Hydrogen atoms are able to penetrate the molecular structure of some metals, especially in cases where physical stresses from extreme temperatures or elevated pressures exist.

- **Damage from Extreme Cold (Unique to Liquid Hydrogen)**
  - Uninsulated lines or storage containers containing liquid hydrogen may cause the air outside the pipe to liquefy and freeze. Vents, valves, and other components associated with systems that use liquid hydrogen could become blocked or damaged due to accumulation of ice.

Common Hydrogen Properties

	Hydrogen	Natural Gas	Gasoline	Propane
Phase at NTP	Gas	Gas	Liquid	Gas
Specific Gravity (air = 1.0)	.0.070	0.60	0.713	1.562
Specific Volume (m^3/kg at NTP)	11.125	1.536	1.429	0.510

- Hydrogen is an extremely light weight gas.
- Because of its light weight, hydrogen dissipates quickly when released. It is so light that uncombined hydrogen can escape the earths atmosphere. Hydrogen will not pool at the ground level.
- Hydrogen has a very small molecular dimension which allows it to migrate through very small openings.
- Because of its low density efficient transport and storage requires that hydrogen be in the form of a high-pressure gas (5,000-10,000 psi) or in its liquid phase.

Common Hydrogen Properties

	Hydrogen	Natural Gas	Gasoline	Propane
Flammable Range (% -by volume in air)	4 – 74	5.3 – 15	1.4 - 7.6	2.2 - 9.5
Ignition Energy (milli joules)	0.02	0.29	0.24	0.26
Auto Ignition Temp (^oF)	968	1004	495	850-950

- **Hydrogen has a very wide flammability range. Higher lean flammability limits means that hydrogen and NG are less likely than gasoline and propane to ignite when small leaks occur. But, large energy accumulation are also not a prerequisite for ignition. Passive and active ventilation strategies could mitigate risk.**
- **Hydrogen requires very low energy to ignite accumulations in its flammability range. The ignition energy is well within the range of static electric discharges and sparks from electrical contacts and switches.**
- **Hydrogen has a fairly high auto ignition temperature an intrinsic safety benefit and one of its attributes as a heat transfer fluid.**

Common Hydrogen Properties

	Hydrogen	Natural Gas	Gasoline	Propane
Heat of Combustion ((HHV) BTU/lb)	61,062	23935	20750	21669
Volumetric Energy Density ((HHV) BTU/scf @ 30 Mpa)	318.1	449.915	1295.638	1109.297

- Hydrogen has a tremendous amount of energy per unit mass, approximately twice that of NG and three times that of gasoline.
- Hydrogen has a very low amount of energy per unit volume, approximately one-third less than that of NG and one-forth that of gasoline.
- Because of these properties its is difficult to transport and storage hydrogen efficiently.

Common Hydrogen Properties

	Air	Hydrogen	Natural Gas	Gasoline	Propane
Thermal Conductivity (Kcal/m hr ºK)	TBA	0.157	$1.15 * 10^{-3}$	$2.85 * 10^{-3}$	
Kinematic Viscosity (kg/m-hr)	TBA	33.84x10-3	0.04176	1.332 - 1.584	0.028904
Diffusion Coefficient in air (inches squared/second)	TBA	0.0946 b	0.0248 b	0.008 b	0.017 c

- Hydrogen has the highest thermal conductivity of any gas, (seven times that of air), which translates to exceptional transfer capabilities.
- Hydrogen has a low viscosity – only one-half the kinematic viscosity (recheck units and values to confirm kv, and value of including) of air.
- Hydrogen has the highest diffusivity of all compounds, four times more than NG in air – thus hydrogen mixes and dissipates quickly, and it can permeate through materials.

Common Hydrogen Properties

Chemical Reactivity

- **Hydrogen is very chemically reactive, and it has a strong affinity for oxygen. On earth it is found bound up with other elements in compounds (e.g. water, H_2O; Ammonia, NH_4, etc.).**
- **When hydrogen reacts with oxygen (combustion or electrochemically) to generate energy, the resulting reaction product is pure water vapor.**
- **Combustion reactions result in no particulate matter – resulting in fires that are nearly invisible and have minimal radiant heat.**
- **Hydrogen acts as an oxidizing agent (receives electrons) when it combines with metals and a reducing agent (donates electrons) when it reacts with nonmetals.**

Common Hydrogen Properties

Metallic Reactivity -- Embrittlement

- Hydrogen atoms are able to penetrate the molecular structure of some metals, especially in cases where physical stresses from extreme temperatures or elevated pressures exist.
- Embrittlement can seriously reduce the ductility and load-bearing capacity, cause cracking and catastrophic brittle failures at stresses below the yield stress of susceptible materials.
- This phenomenon is not completely understood and its detection is very difficult.
- Metals are not affected equally.
  - The most vulnerable are cast iron, high-strength steels, titanium alloys and aluminum alloys.
  - The non-affected metals include, Austenitic SS, Copper, and Aluminum.

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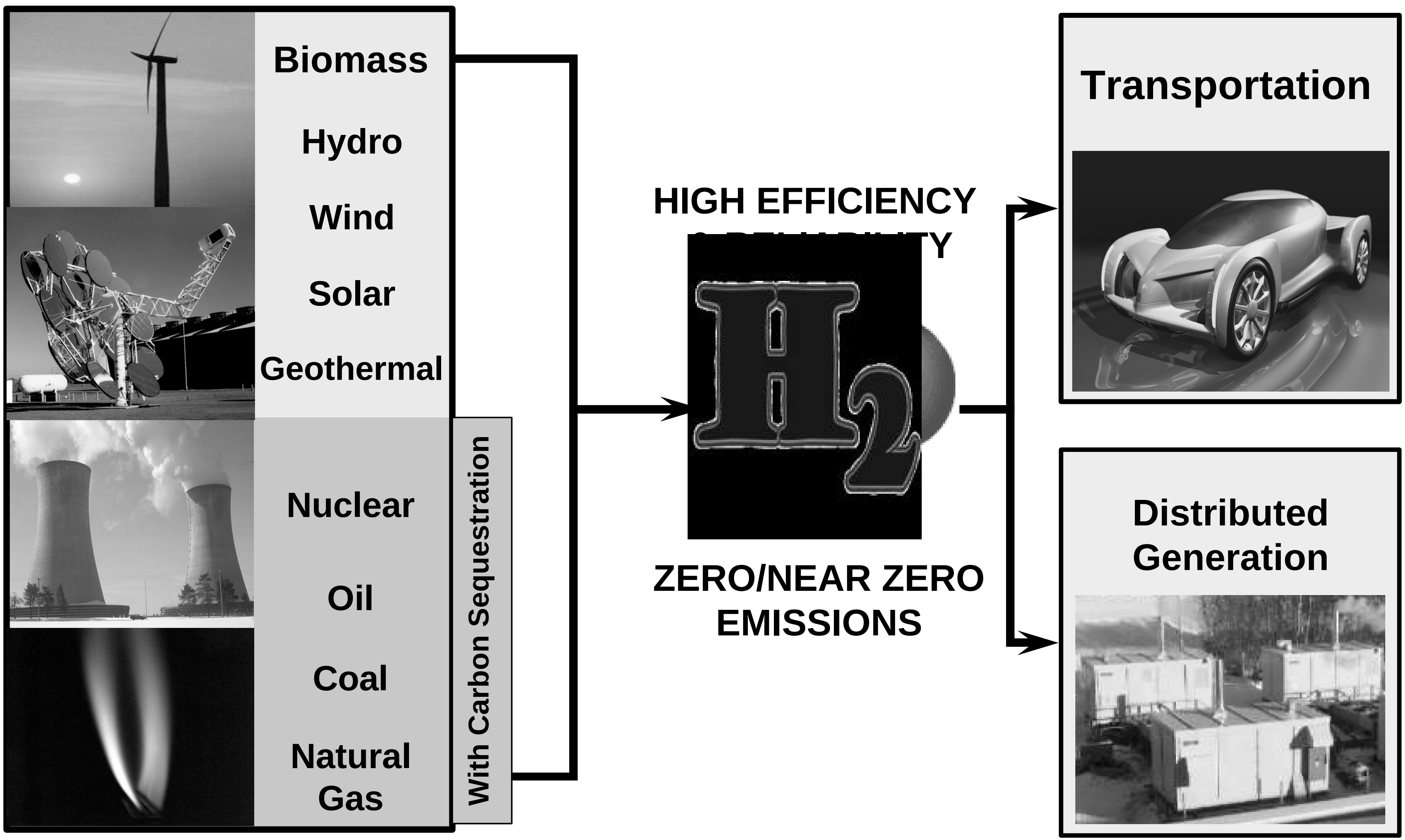
Module I

Introductory Information

Why are we here?

- There is increased discussion on the possible future use of hydrogen as an energy carrier and transportation fuel.
- Many Countries are aggressively pursuing the development of hydrogen energy technologies for wide-scale commercial introduction by 2015.
- The development and transition to a new transportation fuel and fuel delivery infrastructure will require the development of new technologies and equipment; appropriate safety procedures; necessary codes, standards and regulations; implementation of new training and certification programs; and information dissemination and public safety campaigns.
- Hydrogen's physical properties and characteristics, define its suitability as an energy carrier and fuel.
- Hydrogen is no more, or no less dangerous than other fuels. For 50 years industry has demonstrated that hydrogen can be used safely by employing proper safety controls.
- This course has been designed as a first-of-a-kind program to inform codes and standards professionals of the development of hydrogen as a fuel.

Why Hydrogen? ***It's <u>abundant</u>, <u>clean</u>, <u>efficient</u>, and can be derived from diverse <u>domestic</u> resources.***



This Course is Designed to:

- Further your knowledge of Hydrogen, its properties and applications, and the codes and standards that are developing to meet the needs associated with its increasing use in industrial application and other future uses.
- Provide participants with an understanding of hydrogen and critical information on its safe handling and use.
- Address commonly asked fuel code interpretation & application questions.

Course Approach

- Instructor & participants will work together for an interactive educational experience
- Course will be:
  - divided into three interactive sections
  - will include mixed lecture & problem solving modules
  - will provide general knowledge and reference information
  - will reference relevant codes and standards
- Participants will gain increased understanding of fuel related issues and hydrogen safety and emergency response information.

Hydrogen Workbook

- A reference book filled with detailed information, articles and other topical information on hydrogen fuel and energy issues.
  - Serves as a compendium to the coursework
  - Provides commentary that explains the reasons for, use of, or application of the hydrogen code and standards
  - Provides photographs and drawings showing equipment and installations
  - Supplements on subjects of special interest

Seminar Modules

MODULE	TYPE	TOPICAL CONTENT
1	Informational	Properties and applications of hydrogen
2	Informational	Regulations, codes, and standards
3	Informational	Storage and piping
4	Informational	Dispensing/transfer operations
5	Interactive	Emergency response procedures
6	Interactive	Hazard Analysis Procedures (failure modes and effects analysis)
7	Informational	Personnel training for installation and operations (including emergency response training, operating procedures, training intervals, and certification)
8	Informational	Facility inspection for enforcement officials
9	Interactive	Facility siting example
10	Informational	Emergency response example
11	Informational	Operations history (overview of existing facilities and their safety record)

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Module VIII

Hazard Analysis Procedures

What Constitutes a Hazard?

- A hazard is a condition or intrinsic property with the potential to cause:
  - Injury or loss of life
  - Damage to property
  - Impact on environment
  - Interruption of business

Categories of Hydrogen Hazards

- Chemical Hazards
  - Asphyxiation (condition caused by insufficient oxygen)
- Physical Hazards
  - Pressure (sound, shrapnel, pressurized stream)
  - Embrittlement (condition of low ductility and cracking resulting from the occlusion of hydrogen in metals, especially steel)
  - Cryogenic burns (resulting from contact with liquid hydrogen)
- Combustion Hazards
  - Detonation (a violent release of confined energy)
  - Deflagration (combustion that propagates through a gas or along the surface of an explosive at a rapid rate driven by the transfer of heat)

What Initiates a Hazard Scenario?

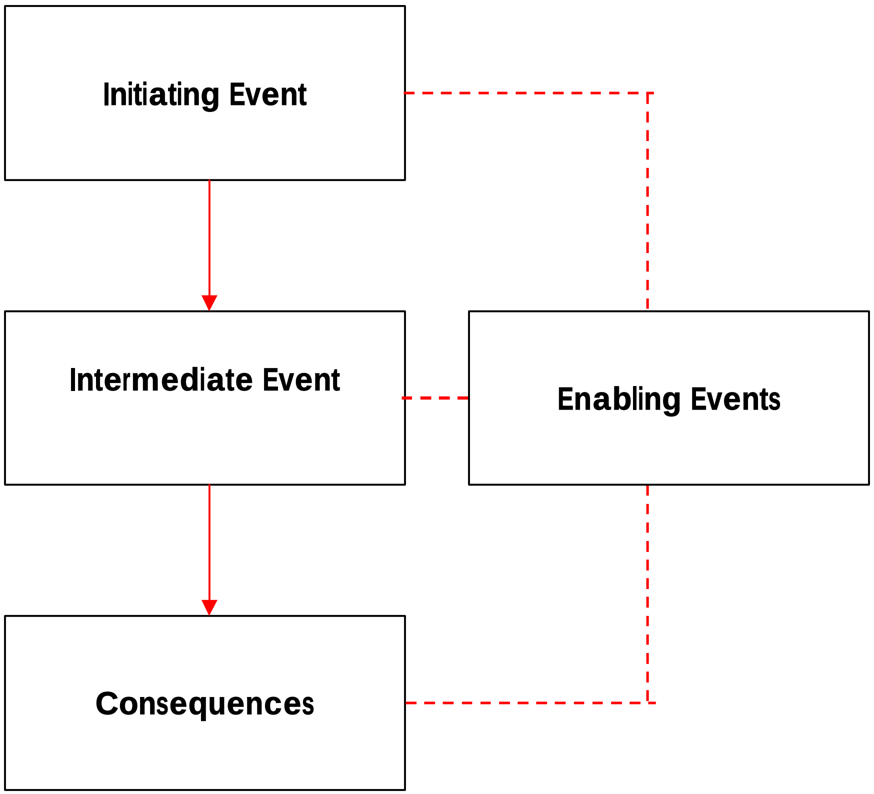
- Hazards arise as a result of:
  - Component failure
  - Operational mistakes
  - External occurrence (natural or man-made including sabotage or attack)

Hazards arise from the use of hydrogen not hydrogen itself.

Methods of Hazard Analysis

- Methods established by industry standards for reliability engineering.
  - Preliminary Hazard Analysis
  - Failure Modes and Effects Analysis
  - Hazard and Operability Analysis
  - Probability Risk Analysis

Hazard Event Sequence



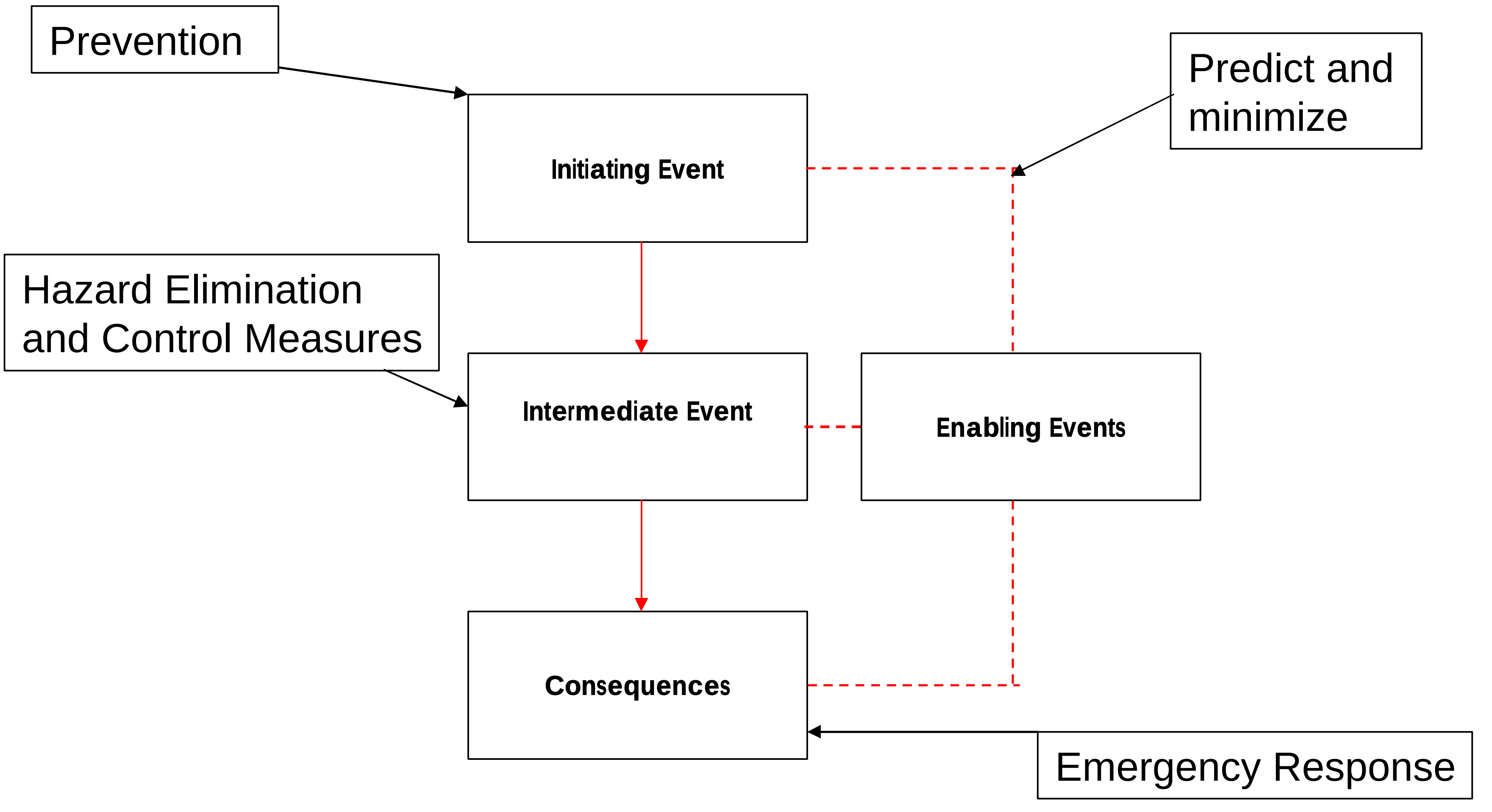
Initiating Event: The cause (component failure – operational mistakes – external occurrence).

Intermediate Event: Process or personnel responses to initiating event.

Enabling Events: Conditions that can contribute to propagation of sequence or lead to other events.

Consequences: Impact of the hazard event. Defined by type and severity.

Where PHA Impacts Hazard Sequence



Preliminary Hazard Analysis

- Identify known hazards
- Determine the cause(s) of the hazards
- Determine the effect(s) of the hazards
- Determine the probability that an accident will be caused by a hazard
- Develop initial design and procedural requirements to eliminate or control hazards

Preliminary Hazard Analysis

- First step in safety process
  - Applied to the conceptual design of a system
  - Describes potential hazards
  - Evaluates the likelihood and severity of safety risks associated with the hazards
  - Used to focus engineering efforts on incorporating measures for mitigating or eliminating potential hazards

Preliminary Hazard Matrix

HAZARD GROUP	POTENTIAL AREAS FOR FAILURE					
	Structural	Electrical	Pressure	Leakage/Spill	Mechanical	Procedural
Collision/Mechanical Damage						
Loss of Habitable Atmosphere						
Corrosion						
Contamination						
Electric Shock						
Fire						
Pathological						
Psychological						
Temperature extremes						
Radiation						
Explosion						

(Adapted from Vincoli, Jeffrey W., *Basic Guide to System Safety*, Van Nostrand Reinhold, New York, New York, 1993, p. 68.)

Hazard Checklist

System/Operation ________________________________

Evaluator ____

Date ________________

Electrical
____ Shock
____ Burns
____ Overheating
____ Ignition of Combustibles
____ Inadvertent Activation
____ Power Outage
____ Distribution Feedback
____ Unsafe Failure to Operate
____ Explosion/Electrical (Electrostatic)
____ Explosion/Electrical (Arc)

Mechanical
____ Sharp Edges/Points
____ Rotating Equipment
____ Reciprocating Equipment
____ Pinch Points
____ Lifting Weights
____ Stability/Topping Potential
____ Ejected Parts/Fragments
____ Crushing Surfaces

Pneumatic/Hydraulic Pressure
____ Overpressurization
____ Pipe/Vessel/Duct Rupture
____ Implosion
____ Mislocated Relief Device
____ Dynamic Pressure Loading
____ Relief Pressure Improperly Set
____ Backflow
____ Crossflow
____ Hydraulic Ram
____ Inadvertent Release
____ Miscalibrated Relief Device
____ Blown Objects
____ Pipe/Hose Whip
____ Blast

Acceleration/Deceleration/Gravity
____ Inadvertent Motion
____ Loose Object Translation
____ Impacts
____ Falling Objects
____ Fragments/Missiles
____ Sloshing Liquids
____ Slip/Trip
____ Falls

Temperature Extremes
____ Heat Source/Sink
____ Hot/Cold Surface Burns
____ Pressure Evaluation
____ Confined Gas/Liquid
____ Elevated Flammability
____ Elevated Volatility
____ Elevated Reactivity
____ Freezing
____ Humidity/Moisture
____ Reduce Reliability
____ Altered Structural Properties(e.g., Embrittlement)

Radiation (Ionizing)
____ Alpha
____ Beta
____ Neutron
____ Gamma
____ X-Ray

Radiation (Nonionizing)
____ Laser
____ Infrared
____ Microwave
____ Ultraviolet

This checklist was adapted from "Preliminary Hazard Analysis (Lecture Presentation)," R.R. Mohr, Sverdup Technology, Inc., June 1993 (Fourth Edition).

PHA Hazard Report

HAZARD REPORT

IDENTIFICATION/TITLE ____________________________

EQUIPMENT/SYSTEM/SYSTEM ____________________

____

PERSON INITIATING REPORT: _______________________

REPORT NO. ________________
DATE INITIATED: ___________
DATE THIS REPORT: ________
SIGNATURE: ________________

CLOSEOUT DATE: ___________

DESCRIPTION OF HAZARD AND ACCIDENT WHICH MIGHT RESULT:

EVENTS AND CONDITIONS WHICH MIGHT CONTRIBUTE TO THE HAZARD OR ACCIDENT:

POSSIBLE MEANS TO ELIMINATE OR CONTROL HAZARD OR ACCIDENT EFFECTS:

ESIMATED PROBABILITY OF ACCIDENT OCCURRENCE:

	CURRENT CONDITION	WITH CONTROL
FREQUENT	______________________	________________
REASONABLY PROBABLE	______________________	________________
OCCASIONAL	______________________	________________
REMOTE	______________________	________________
EXTREMELY IMPROBABLE	______________________	________________

MEANS OF VERIFYING ADEQUACY OF CONTROL/APPLICABLE SAFETY REQUIREMENTS:

ORGANIZATION/PERSON TO TAKE ACTION:

STATUS OF ACTION TO BE OR HAVE BEEN TAKEN:

(Adapted from Hammer, W., *Occupational Safety Management and Engineering, 4th ed.*, Prentice Hall, Englewood Cliffs, New Jersey, 1989, p. 555)

Failure Mode and Effects Analysis

- Identify top level hazards and events
- Identify related equipment component and processes
- Identify potential failure modes and effects
- Identify design inherent safety
- Identify potential prevention and/or mitigation corrective actions

PHA Probabilities

- Probable: likely to occur immediately or within a short period of time
- Reasonably Probable: probably will occur in time
- Remote: possible to occur in time
- Extremely remote: unlikely to occur

Risk Binning Matrix
Frequency/Consequence Criteria

Frequency → / Consequence	Beyond Extremely Unlikely	Extremely Unlikely	Unlikely	Anticipated
High	10	7	4	1
Moderate		8	5	2
Low		9	6	3
Negligible	11	12		

High Risk	Moderate Risk	Low Risk	Negligible Risk

Hazard and Operability Analysis

- HAZOP is recognized as a structured, qualitative analytical tool and is accepted as a part of the risk assessment process which is normally part of a site safety management system.
- The HAZOP analysis technique uses a systematic process:
  - identify possible deviations from normal operations; and
  - ensure that appropriate safeguards are in place to help prevent accidents.

HAZOP

- Define sections
  - Divide system equipment process into sections
  - Use consistent level of detail in describing sections
- Develop credible deviations
- Prepare HAZOP worksheets

HAZOP

- Today the methods of performing HAZOP's may be grouped into four types:
  - Hand written worksheets
  - Spreadsheet programs
  - DOS based programs
  - Windows based programs

- Some of the characteristics of HAZOP that may be considered for differentiating between techniques are:
  - Productivity
  - Auditability of results
  - Quality of documentation
  - Ability for customisation
  - User friendliness and skills required for scribing

Risk Mitigation Plan

- Minimize the greatest risks leading to an unintended release of hazardous material or bodily injury.
- Determine likelihood of occurrence expressed as frequency and severity.
- Identify cause of scenario: initiating event and hazardous material.

Probability Risk Assessment

- Multilevel analysis technique
- Systematically identify possible accident sequences and quantify their probabilities and consequences

Other Types of Hazard Analyses

- Toxic Release Analysis of Chemical Emissions;
  - This state-of-the-art chemical dispersion analysis tool offered by Safer Systems, LLC. evaluates the effect of turbulent diffusion and meteorological conditions upon a chemical release. evaluating the dispersion, explosive, or flammable properties of a chemical. TRACE can be used for facility siting studies, emergency preparedness planning, meeting regulatory requirements and quantitative risk analysis studies. (www.safersystem.com/)