Hydrogen at NASA

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NASA's H_2 Interests

Space Missions and Aeronautic Development

Enable human exploration of the Moon and Mars

Institutional Asset Stewardship

Enhance energy efficiency at all facilities to reduce operating costs and natural resource consumption (e.g. renewable energy sources, alternatively fueled vehicles)

2

Past and Present H_2 Applications

Centaur, Saturn I/IV/V and Space Shuttle transportation (1960 to today)

Gemini, Apollo and Space Shuttle alkaline fuel cells (1965 to today)

International Space Station life support (1999 to today)

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Present H2 Space Applications

Hydrogen used as energy carrier and fuel for spaceport and vehicle applications

For space flight applications, liquefied hydrogen (LH2) has been the traditional method of choice.

Current Primary H_2 Focus

Assurance of liquid hydrogen as fuel for rocket engine tests and Space Shuttle launches.

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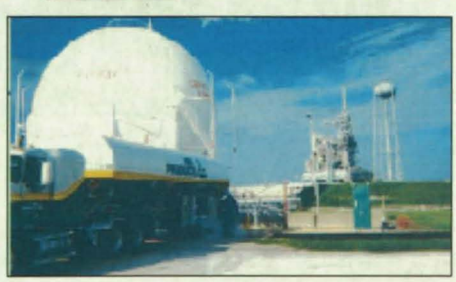
LH_2 Storage

- LH_2 is transferred from tanker trucks to large spherical vessels for storage
- NASA is the largest customer in the US
- Most LH_2 is made commercially from natural gas

Did you know?

Immediately after hurricane Katrina in 2005, 700,000 gallons of LH2 were transferred from KSC to industry to reduce the impact of the temporary reduction in hydrogen production.



Long Term H_2 Goals

In support of human exploration of the Moon and Mars, several technologies are being developed that are based on hydrogen. Much of this effort leverages progress in the commercial sector for use in NASA unique environments and applications

- Hydrogen/oxygen propulsion systems for crew and cargo transportation vehicles
- PEM fuel cells with long life, high-capacity and high-density energy storage for spacecraft and planetary surface exploration
- Solid Oxide Fuel Cells for Aeronautics
- Cryogenic fuel storage
- Local resource extraction from Moon and Mars soil (hydrogen/oxygen for propellant, fuel cells & breathing)

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Long Term H_2 Goals

Space Exploration Resources

Confirming abundant water on the Moon would greatly simplify human life support and transportation by minimizing costly replenishment from Earth. In-situ processing (electrolysis or thermo-chemical) could convert water to hydrogen and oxygen for storage and use as rocket propellant, fuel cell reagents and breathing gas. Even without water, oxygen can be produced from lunar soil.

While lunar samples returned by the Apollo missions revealed that the Moon interior is devoid of water, subsequent robotic surveys (Clementine and Lunar Prospector) indicate the possibility of water ice in the cold dark areas of the lunar poles. If confirmed, the ice may be due to solar wind or past impacts with water rich comets. Estimates suggest there may be the equivalent a small lake (~ 1 billion cubic meters). If true, this much water would provide resources for many lunar and Mars exploration missions.



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Alternatively Fueled Vehicles

Since 1999 Kennedy Space Center (KSC) has demonstrated hydrogen and fuel cell powered vehicles on the center and at the Visitor Complex. NASA plans to move from short-term demonstrations toward implementing hydrogen and fuel cell powered vehicles as a practical part of the vehicle fleet.

H_2 For Ground Facilities

While NASA's resources are limited for institutional improvements, there is interest in outfitting various NASA field centers with hydrogen capabilities. Several centers have resident expertise in hydrogen systems and existing hydrogen infrastructure.

White Sands Test Facility (WSTF) plans a wind energy project for ground water remediation that could include fuel cell energy storage/conversion.

- Multiple centers have proposed the addition of hydrogen fueling stations for use with commercially provided demonstration vehicles.
- Other applications are possible (backup power supplies, utility carts, lawnmowers, etc)

Other H_2 Activities (Past and Current)

- **Collaborations with Universities, Industry, and Government Agencies**
- **Safety**
  - **Standards**
  - **Training**
  - **Testing**
  - **Hazard Analysis**

- **Technology Development**
  - **Fuel Cells** (e.g. PEM, electrode catalysts, membrane electrolytes, solid oxide, methane, metal-air)
  - **Storage** (e.g. metal hydrides, zero-boil off liquids, thermal simulation, carbon sorbents, insulations)
  - **Production** (e.g photo-chemical water splitting, ceramic membranes)
  - **Leak sensors** (e.g. solid state electronics, paint pigments)

- **Technology Transfer to Industry** (e.g. private and public transport)
- **Prize Competitions** (e.g. orbital liquid fuel depot, lunar rover power)
- **Outreach** (e.g. vehicle demos, K-12 education)

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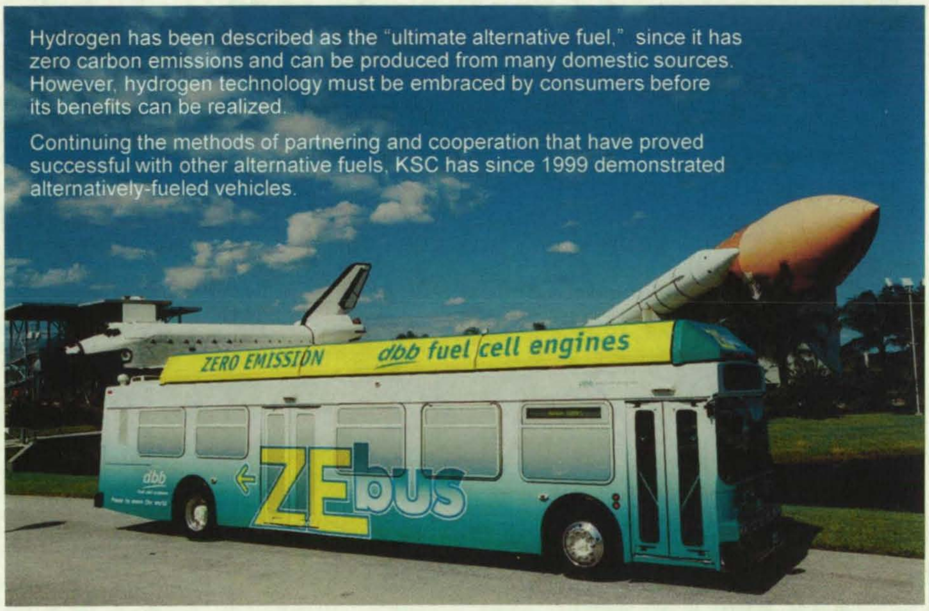
KSC Alternatively Fueled Vehicle Demonstrations

Since 1999 Kennedy Space Center (KSC) has demonstrated hydrogen and fuel cell powered vehicles on the center and at the Visitor Complex.



KSC has been an early adopter of alternatively fueled vehicles since 1994 when the natural gas fueling station was built, allowing NASA to:

- relate the use of hydrogen fuel as a ground transportation fuel to its experience in using hydrogen as an aerospace transportation fuel
- evaluate the use of hydrogen fueled vehicles in its fleet operations,
- comply with Alternative Fuel Vehicles (AFVs) mandates.

KSC, a high-visibility facility with many visitors, has the opportunity to demonstrate to the public at large that these new technologies exist, provide significant benefits, and can gradually gain acceptance for widespread use.

Zero Emission fuel cell bus at KSC for 1 week in 1999

Fuel cell powered vehicle at KSC for 1 week in 2004

In 2004, the fuel cell powered Ford Focus FCV was demonstrated and exhibited on the center and at the Visitor Complex.


FUEL CELL
Ford
HYDROGEN
FUEL CELL

Two fuel cell powered vehicles at KSC for 8 weeks in 2005

In 2005, two Honda FCXs powered by fuel cells were demonstrated at KSC.

LH2 fueled vehicles at KSC for 6 weeks in 2007

In 2007, four hydrogen internal combustion engine (ICE) BMW Hydrogen 7's were demonstrated at KSC.

KSC's first LH2 fueling of a vehicle that's NOT a spacecraft!

These vehicles are fueled with liquid hydrogen (LH2). BMW brought their refueling dispenser/ equipment and KSC supplied the LH2.

Hydrogen refueling capability

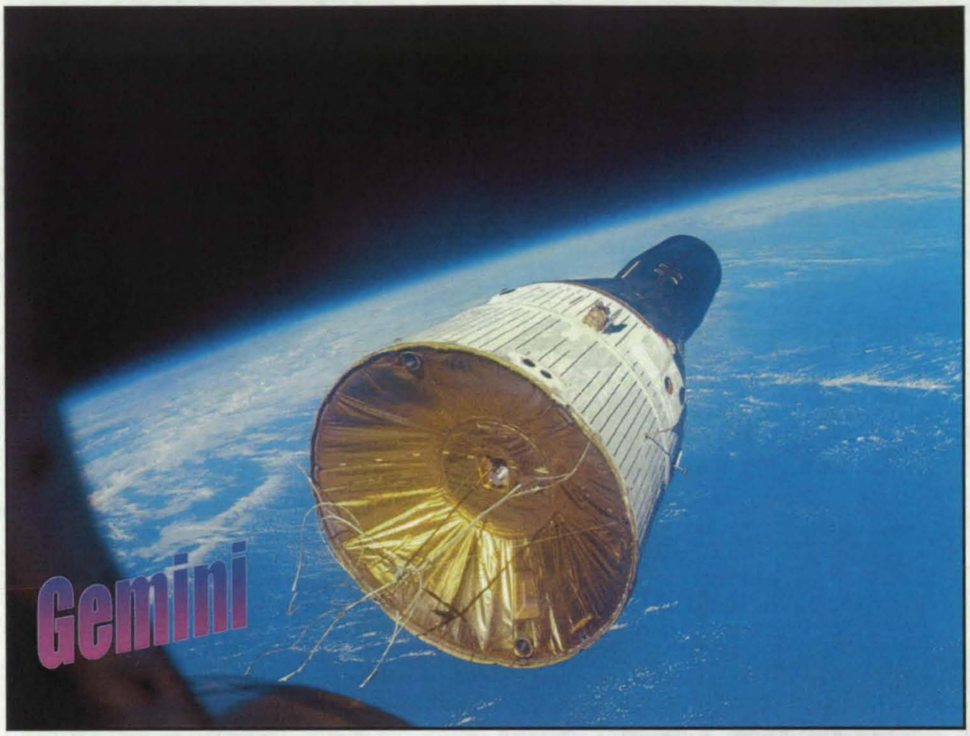
- While NASA resources are limited for institutional improvements, there is interest in outfitting various NASA field centers with hydrogen capabilities.
- KSC now has 350bar (5,000psi) refueling capability and is working toward early adoption of hydrogen vehicles
- Stennis Space Center and Marshall Space Flight Center also use large quantities of hydrogen and are good candidates for early adoption of hydrogen vehicles
- Several centers have proposed adding hydrogen fueling stations for use with commercially provided demonstration vehicles. Other applications are possible (backup power supplies, utility carts, lawnmowers, etc).

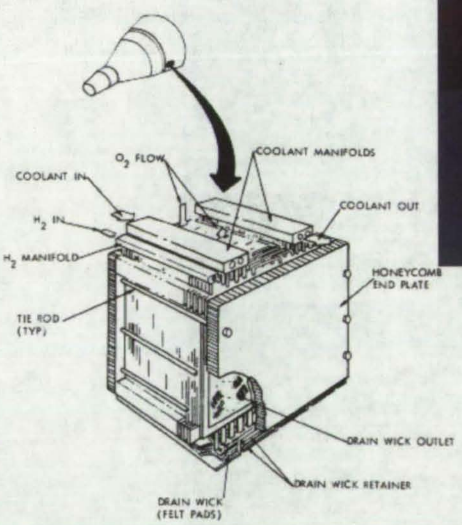
Hydrogen Fueling Station at Proton Energy – Wallingford, CT

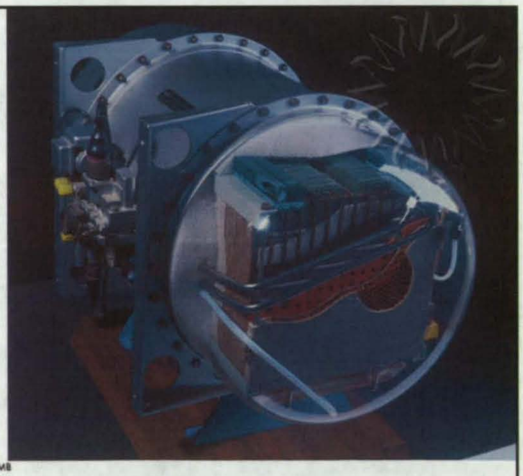
A Pictorial History of Fuel Cells at NASA

The once obscure fuel cell was refined/developed by NASA to solve the dilemma of how to provide power for extended missions to space.

Gemini





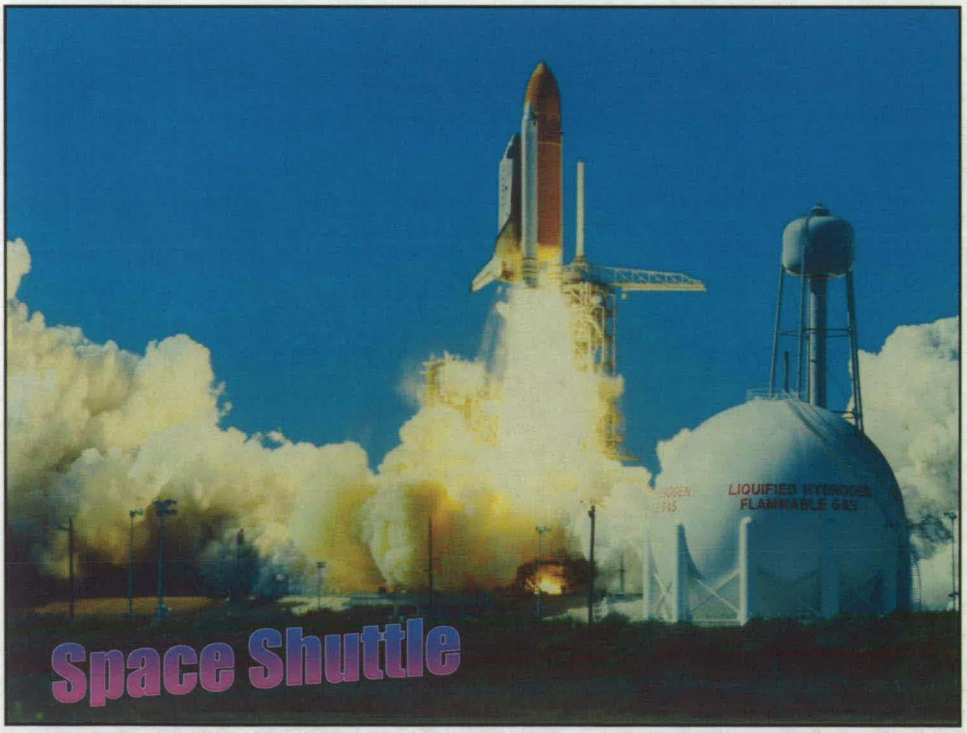


Gemini Fuel Cell


Fuel cells helped achieve mission success


Apollo
NASA


NASA
Apollo Fuel Cell


LIQUIFIED HYDROGEN
FLAMMABLE GAS
Space Shuttle

Space Shuttle Fuel Cell

Future Missions

- Altair lunar lander as currently planned will use a PEM fuel cell.

Artist's concept of a lunar lander on the moon's surface.

Since refinement/development by the space program, fuel cell technology has achieved widespread recognition by academia, industry, and government as a means for producing clean energy for the future. NASA is open to collaborations that benefit its goals and those of the nation.

Acquisition and Distribution of Liquid Hydrogen

- NASA is the largest consumer of liquid hydrogen (LH_2) in the US.
- NASA has purchased over 350 million pounds over 45 years, with millions of miles of safe delivery by truck, rail, and barge.
- KSC manages contracts, and monitors markets and technologies for availability, costs, detection, production, safety, storage, and transport.

Tanker being filled before delivery.
Tanker trucks are so well insulated that they can haul LH2 for hundreds of miles without losses to boil-off.

Liquid Hydrogen Delivery

LH2 is transported from commercial vendors to NASA Centers on the public roads via cryogenic (having very low temperatures) tanker trucks.

Approximately 50 tanker trucks are driven in for each shuttle launch to provide the necessary LH2.

Shuttle main engines burn about 500,000 gallons (295,000 lbs) of LH2. Another 239,000 lbs are lost due to boil off and transferral. The fuel is stored at minus 423°F. The engine exhaust is primarily water vapor.

LH2 tankers at destination prepare to fill 850,000 gallon storage tank.

On-site Distribution

Stennis Space Center uses barges for on-site distribution.

All other sites use tankers and fixed storage.

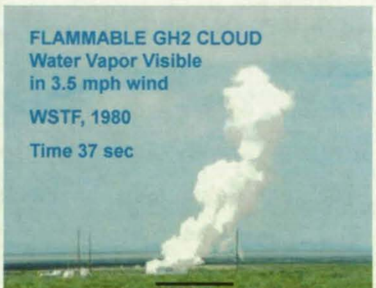
Storage tank at KSC

White Sands Testing Facility and Hydrogen

Testing

White Sands Test Facility (WSTF) has a wide variety of resources to draw upon in assessing the fire, explosion, compatibility, and safety hazards of hydrogen and other propellants.

2000 lb LH2-Lox Launch Accident Simulation



Safety Standards

The White Sands Test Facility collaborates with a variety of organizations to ensure up-to-date safety information and standards for Agency use and share NASA hydrogen expertise in the development of national and international standards:

- WSTF Personnel hold Chairman and Secretary duties for AIAA's Hydrogen Committee on Standards: "Guide to Safety of Hydrogen and Hydrogen Systems, (ANSI/AIAA G-095-2004)"
- Share hazards research and best practice experience: DOE, Sandia National Laboratories, and Pacific Northwest National Labs
- ISO Technical Committee 197 Hydrogen Technologies: "Basic considerations for the safety of hydrogen systems, (ISO/PDTR 15916)"
- American Society for Testing and Materials
- National Fire Protection Association: Hydrogen Technologies (NFPA 2) standard in development

Training

WSTF has provided safety training courses in specialized areas since 1987

- Taught at NASA centers, government and industry locations
- Customized content can be arranged

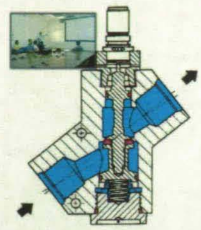
- Hydrogen courses currently offered through the NASA Safety Training Center (NSTC) or by special arrangement:
  - Hydrogen Safety [2-day seminar (037 - NSTC)]
  - Safety in Hydrogen Systems Operations [4-hour instruction (054 - NSTC)]
- Other courses offered include: Oxygen Safety, Hypergol Safety, and COPV Inspection

Hazard Assessment

Experience in performing hydrogen hazard assessment on components, systems, and facilities using specially developed protocols:

[Hydrogen Hazards Assessment Protocol for Components and Systems (WSTF-IR-1117-001-08)]

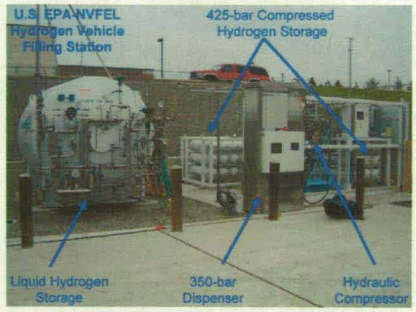
Component Analysis



Analysis considers:

- Environment and Operating conditions
- Material compatibility
- System design and best practice
- Flammability, Ignition, & explosion
- Exposures to personnel and equipment
- Consequences (before and after mitigations)

Provides logical methodology, documentation of findings, mitigations and recommendations



Facility Siting Assessment, Ann Arbor, Michigan