- Energy Content: 60,958 Btu/lb – highest energy content of all fuels on a **weight** basis
  - This is why NASA uses hydrogen – they care a lot more about weight than volume
  - Energy content is about three times higher than gasoline, natural gas, and propane on a **weight** basis
  - Energy content is only about one third that of natural gas and about an eighth that of propane on a **volume** basis
- Flammability limits (in air): 4.1 v% - 74 v%
- Explosion limits (in air): 18.3 v% - 59 v%

Hydrogen vs. Methane and Petrol

Property	Hydrogen	Methane	Petrol	Units
Molecular Weight	2.016	16.043	107	amu
Normal boiling point (nbp) temperature	20.268	111.632	310 to 478	K
Critical pressure	12.759	45.387	24.5 to 27	atm
Critical temperature	32.976	190.56	540 to 569	K
Density at critical point	0.0314	0.1604	0.23	g/cm3
Heat of fusion	58.23	58.47	161	J/g
Heat of vaporization	445.59	509.88	309	J/g
Heat of combustion (low)	119.93	50.02	44.5	kJ/g
Heat of combustion (high)	141.86	55.53	48	kJ/g
Energy of density	8.49	21.14	31.15	MJ/litre
NBP = Normal boiling point				
NTP – 1 atm and 20°C (293.5K)				

Hydrogen's Properties

Hydrogen is a colourless, odourless, tasteless, and nonpoisonous gas under normal conditions on Earth.

Hydrogen is highly flammable; it only takes a small amount of energy to ignite it and make it burn. It also has a wide flammability range, meaning it can burn when it makes up 4 to 74 percent of the air by volume.

Hydrogen burns with a pale-blue, almost-invisible flame, making hydrogen fires difficult to see.

The combustion of hydrogen produces no carbon dioxide (CO2), particulate, or sulfur emissions. It can produce nitrous oxide (NOX) emissions under some conditions.

The energy in one gallon of petrol is roughly equivalent to 1 kg of Hydrogen.

Typically, a petrol internal combustion engine (ICE) is 18-20% efficient; hydrogen ICEs are about 25% efficient; methanol fuel cells are about 38% efficient; and hydrogen fuel cell vehicles like Toyota's FCHV-4 are 60% efficient—3 times better than today's petrol fueled engines.

The amount of energy produced by hydrogen per unit weight of fuel is about 3 times the amount of energy contained in an equal weight of petrol, and almost 7 times that of coal.

Hydrogen energy density per volume is quite low at standard temperature and pressure. Volumetric energy density can be increased by storing the hydrogen under increased pressure or storing it at extremely low temperatures as a liquid.

- Uses, Today and Future
  - **Today: chemical processing, petroleum industry, fats and oils, metals, electronics, space flight, utilities, glass manufacturing, and others**
  - **Future: stationary power, portable power, and transportation.**
- Production
  - **Today, mainly through reformation of fossil fuels**
  - **Industrial by-product**
  - **Future, from renewables as well as fossil fuels with carbon sequestration**
- Properties
  - **Hydrogen is the lightest, most basic, abundant element**
  - **Properties are unique - must be treated appropriately**

Using Hydrogen energy could help address many concerns facing our nation and the world.

Hydrogen can be made from a variety of domestic feedstocks like water, biomass, coal and natural gas.

Hydrogen is non-toxic, non-poisonous and will not contribute to groundwater pollution. It does not create "fumes" or other harmful emissions; in fact, using hydrogen in fuel cells produces only electricity and pure water.

Hydrogen is a key enabler for the development and more widespread implementation of renewable energy technologies, resulting in cleaner and more efficient products in the marketplace.

Fifty million tons of hydrogen are produced each year worldwide. The challenge is to bring hydrogen into the everyday lives of customers as they begin to use hydrogen-powered vehicles and other applications.

Endpoint: A Diverse Portfolio Of Feedstocks and Technologies

- As much renewable energy as practical
- Coal with carbon sequestration
- Nuclear with issues resolved
- Natural gas plays key role in early years

Hydrogen Vehicles

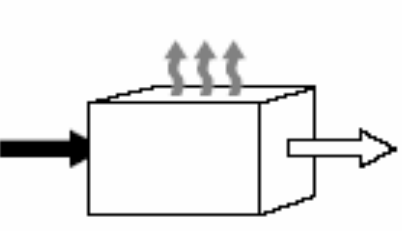
Technologies

–ICEs

–Hybrids

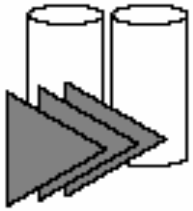
–Fuel Cells

The Generic Hydrogen Station



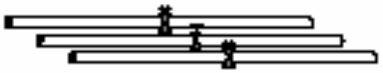
Hydrogen Generator

Electrolyzers
Reformers



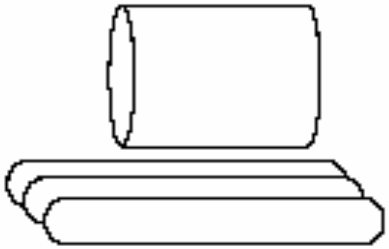
Auxillary Equipment

Pressure Swing Absorbers, Compressors



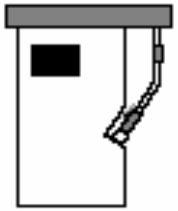
Hydrogen Piping and Distribution

Low and high pressure hydrogen safe piping and valving



Hydrogen Storage

Cryogenic, low and high pressure gaseous hydrogen vessels



Compressed H_2 Dispenser

cryogenic, 250 - 700 bar gaseous hydrogen units

Vehicle Interface

nozzle, receptacle, user interface

- **Converts utility grid inputs to hydrogen**
- **Or delivered by truck**

- **PSA = Fuel quality control**
- **Compressor = More fuel in less space**

- **Moves hydrogen between equipment**
- **Safety valves & vents**

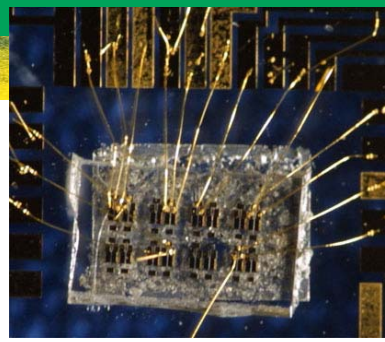
- **Safely stores fuel**
- **Sets station vehicle capacity**

- **Delivers fuel to vehicle**
- **Controls access**

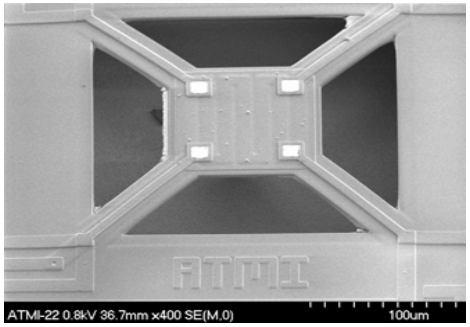
- **Human point of contact**

Liquefaction

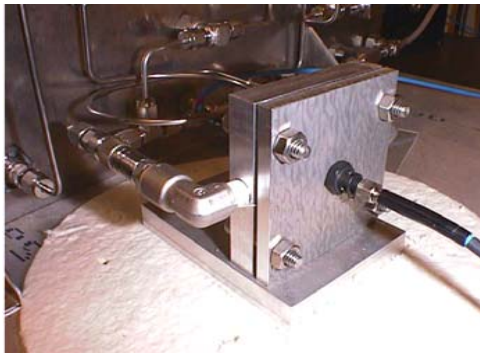
- On 10 May 1898, James Dewar used regenerative cooling to become the first to statically liquefy hydrogen. Using liquid nitrogen he pre-cooled gaseous hydrogen under 180 atmospheres, then expanded it through a valve in an insulated vessel, also cooled by liquid nitrogen. The expanding hydrogen produced about 20 cubic centimetres of liquid hydrogen, about 1 percent of the hydrogen used.
- The insulated vessel Dewar used became known as "Dewar flasks," now simply dewars. His design was a very significant contribution to the storage and transportation of very cold liquefied gases such as oxygen, nitrogen, air, hydrogen, fluorine, and helium. Dewars are double-walled vessels with a vacuum in the annular space to minimize heat transfer by conduction and convection. The walls are silvered to reflect radiant heat. Dewar vessels, with engineering refinements, are used today to transport liquid hydrogen with very low loss rates.



- Odorants
  - Suitable for Natural Gas industry
  - Diffusion/dispersion matching is difficult with hydrogen
  - Poison to fuel cell?



- Sensors
  - Safe, reliable, cheap sensors being developed
  - Placement is important



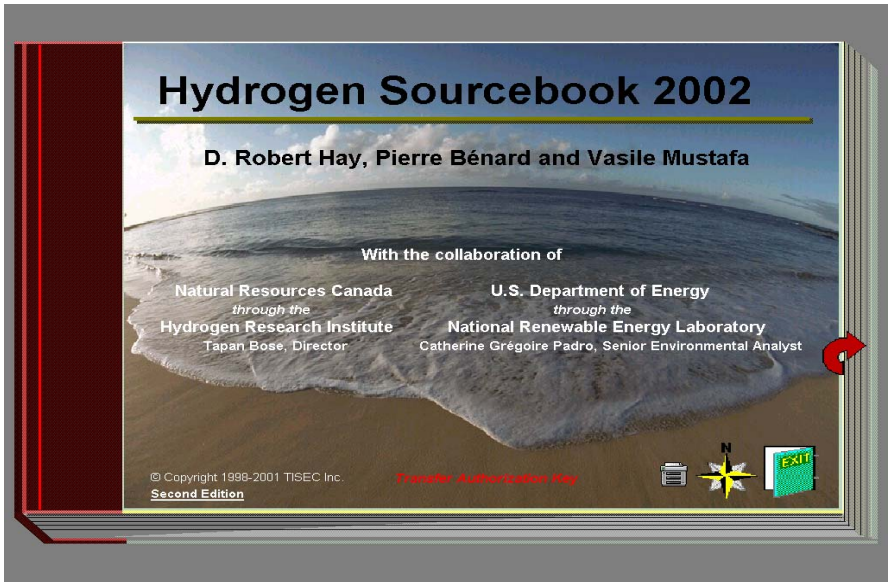
- HYSAFE – Safety and validation work in Europe and with international partners
- HYAPPROVAL - Handbook for Approval of Hydrogen Refuelling Stations (under European Commission FP6 contract N° 019813)
  - The aim of the project is to make a "handbook for approval of Hydrogen refuelling stations" which will be used to certify public hydrogen filling stations in Europe.

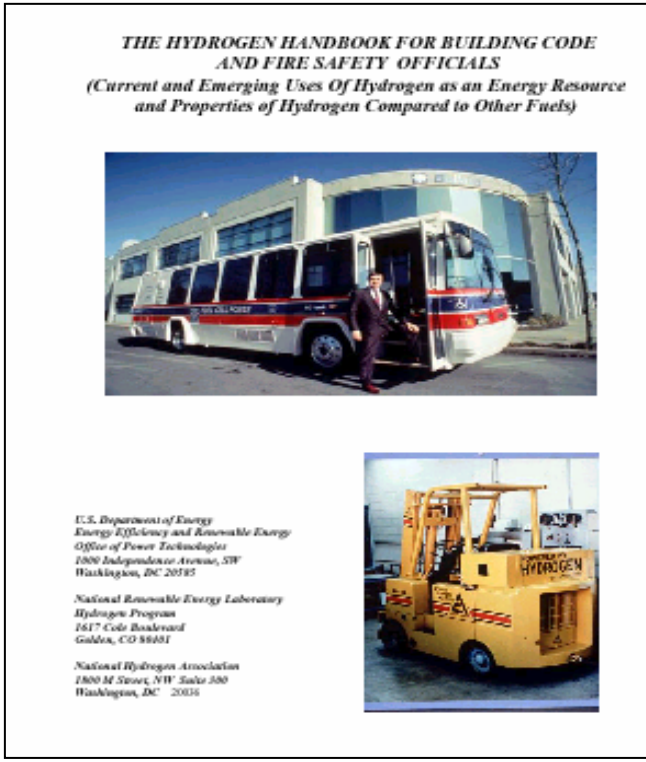
International Efforts

- **APEC Countries are updating the Sourcebook for Hydrogen Applications to include valuable regulatory, codes, and standards information on hydrogen energy projects in APEC countries.**
  - **The Sourcebook is available at www.TISEC.com**
- **The European Hydrogen Association**
- **The UK is developing a guideline for installation of hydrogen fuel cells**
- **The EU has a program called HySafe that seeks to create a database of hydrogen incidents.**
  - **The main objective of the HySafe network is to strengthen, integrate and focus fragmented research efforts to provide a basis that will allow removal of safety-related barriers to implementation of hydrogen as an energy carrier. In this way the network will also contribute to promoting public awareness and trust in hydrogen technology within Europe by providing a basis for communicating the risks associated with hydrogen.**
  - **See www.HySAFE.org**
- **The US DOE has just announced a hydrogen incidents database at www.h2incidents.org**

Existing Guidelines for Hydrogen Systems

- The Hydrogen Handbook for Building Code and Fire Safety Officials
- The Hydrogen Sourcebook





Safety, Codes & Standards Resources

www.Hydrogenandfuelcellsafety.info

www.HydrogenAssociation.org

- *Hydrogen & Fuel Cell Safety Report*
- NHA Website
- Sourcebook for Hydrogen Applications
- Regulator's Guide to Permitting Hydrogen Applications – including hydrogen refueling stations
- European Hydrogen Association
- US Model Codes
- CaFCP
- SAE
- International Efforts

- An online resource for Hydrogen & Fuel Cells Codes & Standards information
- Monthly electronic publication of the National Hydrogen Association (NHA)
  - Latest Issue
  - Archives – search engine
  - Documents for Review
  - Technical Resources
  - http://www.hydrogenandfuelcellsafety.info
  - Sign-up for automatic e-mail notification

- Technical Resources
  - CaFCP commissioned studies
  - Emergency response materials
    - First Responder Training
    - Emergency Response Guide
    - Additional training materials in development
  - Fuel Cell Transit Bus Coordination and Evaluation Plan
  - California fuel station and demonstration program map
  - How a fuel cell works - animation
- Technical Fact Sheets
  - Hydrogen Station Test Apparatus
  - Hydrogen Quality Sampling Adapter
- Organizational Resources
  - CaFCP general presentation - coming soon
  - CaFCP brochures
  - CaFCP fact sheets
  - CaFCP images and videos
  - www.fuelcellpartnership.org

Additional Information

- Monthly electronic Hydrogen Safety Newsletter – The Hydrogen & Fuel Cell Safety Report – www.HydrogenandFuelCellSafety.info
- User-Friendly Codes and Standards Matrix – www.fuelcellstandards.com
- European Hydrogen Association www.h2euro.org
- US National Hydrogen Association www.hydrogenassociation.org
- Khall@ttcorp.com