Hydrogen: The Future of Energy?

Jerald A. Cole
Chief Technology Officer
Hydrogen Ventures

Whittier Sunrise Rotary
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Facts About Hydrogen Today

• Where does it come from?
• Amount Produced
• Total Market Value
• Key Markets and Uses
Facts About Hydrogen Today

• *Where does hydrogen come from?*

• Hydrogen is abundant
  – Accounts for 70 percent of the known universe
  – On Earth, however, it is a distant 10th place
    • Still, very easy to find!
  – Produced mainly from natural gas
  – Other sources:
    • Electrolysis of water
    • Byproduct of chemicals production
Facts About Hydrogen Today

• How much is made?
• World production (2001): 540 billion m³/y
• Excluding ammonia production: 260 billion m³/y

(Source: Air Liquide)
Facts About Hydrogen Today

- **What does it cost?**
  - **Production cost**
    - Typically about 18 – 20 ¢/100 cu. ft.
  - **Delivered costs**
    - Very large volumes - $0.60 - $0.70/100 cu. ft.
    - In smaller volumes easily 10 times as much
  - **World production amounts to about $3 billion**
    - Point of sale value closer to $10 billion

**Gallon of gasoline equivalents:**
- Production cost 85 ¢/gal
- Delivered cost $2.50 - $3.00/gal
Facts About Hydrogen Today

(Source: Air Liquide)
Hydrogen Safety

• Hindenburg Syndrome

• Physical Aspects
  – Confined Space Explosions
  – Comparative Effects – Radiation
  – Smoke, Asphyxiation
Hydrogen Safety

- **The Zeppelin** *The Hindenburg*
  - Contained 7 million cu. ft. of hydrogen
  - Burned and crashed in Lakehurst NJ on 6 May 1937
  - 62 survivors
  - 35 dead
    - One was burned
    - 34 jumped or fell
  
  *Cause of fire has now been attributed to the cellulose acetate/aluminum coating on the skin of the aircraft*
Hydrogen Safety

• Other Safety Issues

• Confined space explosions
  – Not as likely with hydrogen

• Radiation
  – Major source of injury or damage with common fuels
  – Virtually non-existent with hydrogen

• Smoke, asphyxiation
  – No inhalation hazard from hydrogen itself
  – Few harmful products of combustion
Hydrogen Safety

• **Comparative flame properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Gasoline</th>
<th>Methane</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flammable Limits In Air (vol %)</td>
<td>1.0 - 7.6</td>
<td>5.3 - 15.0</td>
<td>4.0 - 75.0</td>
</tr>
<tr>
<td>Ignition Energy In Air (Mj)</td>
<td>0.24</td>
<td>0.29</td>
<td>0.02</td>
</tr>
<tr>
<td>Ignition Temperature (°C)</td>
<td>228 - 471</td>
<td>540</td>
<td>585</td>
</tr>
<tr>
<td>Flame Temperature In Air (°C)</td>
<td>2197</td>
<td>1875</td>
<td>2045</td>
</tr>
<tr>
<td>Explosion Energy (g-TNT/kJ)</td>
<td>0.25</td>
<td>0.19</td>
<td>0.17</td>
</tr>
<tr>
<td>Flame Emissivity (%)</td>
<td>34 - 43</td>
<td>25 - 33</td>
<td>17 - 25</td>
</tr>
</tbody>
</table>

Hydrogen safety issues are *different* than those of other fuels.
## Hydrogen and Fuel Cells

<table>
<thead>
<tr>
<th>Fuel Cell Type</th>
<th>Fuel Used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hydrogen</td>
</tr>
<tr>
<td>PEM</td>
<td>✓</td>
</tr>
<tr>
<td>Metal Air</td>
<td>×</td>
</tr>
<tr>
<td>Direct Methanol</td>
<td>×</td>
</tr>
<tr>
<td>Alkali</td>
<td>✓</td>
</tr>
<tr>
<td>Phosphoric Acid</td>
<td>✓</td>
</tr>
<tr>
<td>Molten Carbonate</td>
<td>×</td>
</tr>
<tr>
<td>Solid Oxide</td>
<td>○</td>
</tr>
</tbody>
</table>
The Future of Hydrogen

• Where will it come from?
• Renewable Hydrogen?
• Hydrogen as a Fuel
• How Much will be Needed?
The Future of Hydrogen

• **Where will it come from?**

  • Near term
    – Petroleum and natural gas
    – Coal – emerging technologies
  
  • Mid term (< 50 years)
    – Electrolysis
    – Biological production
    – Other renewable sources
  
  • Long term
    – Nuclear
    – Direct solar photolysis

(Source: U.S. DOE)
The Future of Hydrogen

• **Renewable Hydrogen**

• The Goal!

• Definition
  – Hydrogen produced with no *net* release of carbon dioxide to the atmosphere
  – Hydrogen produced from non-fossil resources

• Examples
  – Electrolysis, photolysis
  – Agricultural waste, sewage, biomass
The Future of Hydrogen

• *Hydrogen as a fuel*

• Two modes of use
  – Drop-in replacement for present-day *conventional* fuels
  – Medium for storage of energy
    • *i.e.* for electricity generation

• Environmental effects
  – Some residual effects in most applications
  – Not fully evaluated, needs further study
The Future of Hydrogen

• How much will we need?

• Hydrogen as a transportation fuel

Scenario 1: 10% buses
Scenario 2: +0.1% cars
Scenario 3: +1% cars
Scenario 4: +10% cars

(source: Air Liquide)
The Future of Hydrogen

• *How much will we need?*

• As a transportation fuel
  – Will require about 10x current production
  – Assumes certain increases in vehicle efficiency

• Total Energy Market
  – Will require about 18 – 20 x current production
Summary

• Hydrogen is plentiful
  – Easy to find, produce and store

• Safety concerns
  – We know how to address these

• Environmentally issues
  – Not fully defined, but looks promising

• The Future of Hydrogen
  – Details uncertain
  – Very much a reality