Hydrogen Delivery/Safety

Air Products and Chemicals, Inc.

B. B. Bonner

The American Ceramic Society and ASM International Conference
Material Innovations in an Emerging Hydrogen Economy

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Air Products at a Glance

- US$10B in sales
- Diverse markets and geographies
- Over 50% of our revenues are outside U.S.

FY07 Consolidated Sales
By Reporting Segment

- Merchant Gases (32%)
- Tonnage Gases (26%)
- Electronics and Performance Materials (21%)
- Healthcare (6%)
- Chemicals (9%)
- Equipment and Energy (6%)
Leadership in Hydrogen Fuel Infrastructure

- Worlds largest producer of merchant hydrogen
- Our capacity ~1.75 million TPY Could support 7-8 million vehicles
- Active since 1993
  - Built over 80 hydrogen station projects
  - Exceeded 50,000 fuelings
  - in 12 countries
- Strong and broad IP position.
Emerging Hydrogen Economy Infrastructure Requirements

H₂ Production
- Onsite Reformers
- Electrolyzers
- Gas Separation & Purification Devices
- Central H₂ Production

Storage
- Light weight Vessels
- Metal Hydrides
- Chemical Hydrides
- Carbon

Delivery
- Dispensing Systems
- Compression
- Distribution
Total Safety Philosophy

- Nothing is more important than safety...not production, not sales, not profits.
- All accidents and injuries are preventable...they are not inevitable.
- Safety is a management responsibility and safety can be managed.
- Safety is an individual responsibility...and a condition of employment.
Total Safety Philosophy

- Safety is a way of life around the clock.
- Every task must be performed with a concern for safety...for ourselves, our fellow employees, our contractors, our visitors, our customers, and the communities in which we operate.
- A commitment to Total Safety is a commitment to doing things right the first time.
- Ultimately, this results in elimination of injuries and optimization of all activities.
Properties – H2 is a Fuel

Flammable Range  
4 - 74% by vol. in air

Detonable Range  
18.3 – 59% by vol. in air

- Wide flammability range
- Low ignition energy
- Tendency to ignite before large energy accumulation
- Very hot, invisible flame (pale blue at night)
- Importance of ventilation
- Siting requirements away from ignition sources and compounding hazards
# Properties Comparison

<table>
<thead>
<tr>
<th></th>
<th>H2</th>
<th>NG</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Color</td>
<td>none</td>
<td>none</td>
<td>yes</td>
</tr>
<tr>
<td>2- Toxicity</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>3- Odor</td>
<td>odorless</td>
<td>mercaptans</td>
<td>yes</td>
</tr>
<tr>
<td>4- Specific Gravity</td>
<td>0.07</td>
<td>0.424</td>
<td>liquid</td>
</tr>
<tr>
<td>5- Environment - Leak</td>
<td>none</td>
<td>none</td>
<td>CnHm</td>
</tr>
<tr>
<td>Impact - Fuel</td>
<td>none</td>
<td>CO2 / NOx</td>
<td>CO2 / NOx</td>
</tr>
<tr>
<td>6- Diffusion Coefficient (cm3/s)</td>
<td>0.61</td>
<td>0.15</td>
<td>liquid</td>
</tr>
<tr>
<td>7- Flame Temperature (°C)</td>
<td>2318</td>
<td>2148</td>
<td>2200</td>
</tr>
<tr>
<td>8- Flammability Range (% in air)</td>
<td>4% - 75%</td>
<td>5.3% - 15%</td>
<td>1.4% - 7.6%</td>
</tr>
<tr>
<td>9- Ignition energy (milli Joules)</td>
<td>0.02</td>
<td>0.29</td>
<td>0.2</td>
</tr>
<tr>
<td>10- Auto Ignition Temp. (°C)</td>
<td>520</td>
<td>&lt; 500*</td>
<td>440</td>
</tr>
<tr>
<td>11- Heat Value (kJ/kg)</td>
<td>119,972</td>
<td>50,020</td>
<td>42,847</td>
</tr>
<tr>
<td>12- Energy Density (MJ/Nm3)</td>
<td>10.783</td>
<td>35.882</td>
<td>104.4</td>
</tr>
</tbody>
</table>

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Ignition Energy of H₂, CH₄ and Gasoline with Air

Flammability Limits of H₂ Are Seven Times Wider Than CH₄
Delivered Hydrogen

- Gas Pipeline
- Liquid Tank Trailer
- Gas Tube Trailer
- Mobile Fueler
Total U.S. Hydrogen Production: Approx. 30 Billion SCFD

Hydrogen Consumed Where Produced: 97%

Major Uses:
- Ammonia
- Petroleum Refining
- Food Industries
- Metals Treatment
- Petrochemicals

Merchant Hydrogen (Outside Customers): 3%

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Pipeline Standards and Regulations

- CFR 49 Part 192 and as amended by delegated state agency.
- Air Products standards employ minimum design to Class 3 location except for very remote unpopulated areas and typically exceed the requirements of Part 192.
- Environmental Impact Studies designate additional design considerations.
- Local jurisdictions (City, Township, Parish, County, etc.) have imposed additional requirements beyond basic regulatory requirements.
Pipeline Safety

- Hydrogen Industry Has 500 Miles in U.S.
- Conventional low-carbon steel pipelines.
- Small variation in pipeline pressure pipe (low cyclic stress).
- Existing natural gas pipelines have been successfully converted to hydrogen.
- No Fires at Hydrogen Pipelines in 35 Years at Air Products
Excess Flow Valve (EFV)
Liquid Hydrogen Distribution

Truck in *liquid* hydrogen

delivered at about –423°F and 100 psig.

- SS inner vessel
- CS outer jacket
- Insulation space
- No product release in shipping
- Excellent safety record
Liquid Hydrogen Trailer Safety

- Trailers With Armored Type Construction
  - Inner Tank With Outer Thick Steel Jacket
- 70 Million Gallons of Liquid H2 / Year
- 8 Million Miles / Year
- 160 Million Miles Since Inception Without Loss of Liquid Hydrogen onto the Road
- 1996 NASA Safety Award Winner
  - 200 Million Pounds of Liquid H2 Over 25 Year Period Without a Significant Incident
- Vehicle Accidents Do Occur
Hydrogen Distribution

Truck in *gaseous* hydrogen

- **Standard Tube-Trailer**
  - Delivered at ~ 2600 psig
  - 300 kg capacity

- **Mobile Fueler**
  - Totally self-contained
  - 350 Bar fueling
  - DOT approved
Hydrogen Fueling Station

- Compression and storage modularized
- Hydrogen dispenser typically separate
- Designed for any type of H2 supply mode
- Designed to service small to large fleets of autos and buses
- Wide range of flows
- Electric Drive Compressor

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Hydrogen Fuel Dispensing Stations
General Permitting Comments

- Early systems
  - Engineered to order, remote.
  - Sometimes helped with permitting
    - Little public interaction
  - Understood to be prototypes/R&D

- Newer systems
  - “Real” usage
    - Follow normal process
  - More rigorous review
  - But more knowledge/Codes
Importance of Codes & Standards

- Improves Safety
  - Paramount importance to all
- Provides Education to AHJ (Authority Having Jurisdiction), such as CGA or NFPA pamphlets
- Provides Consistency
- Assists with Permitting, as helps AHJ’s make decisions
- Levels playing field for all participants
- Key to long-term liability issue.
H₂ Fueling Safety - Codes, Standards, and Training

- Adhere to Industrial Codes
  - ASME BPVC, ASME B31.3, NEC (NFPA 70)
- Adhere to Hydrogen Codes
  - NFPA 55, CGA Guidelines
- Apply CNG Fueling Codes Where Applicable
- Active Role in Codes and Standards Development
  - SAEJ2600 & J2601, NFPA 50, NFPA 52
- Provides Comprehensive Safety Training
  - Dispenser, Hydrogen, KnowH₂ow®.
100 Years of Gasoline Fueling
Public Dispensing – 180,000

Hydrogen Fueling in Infancy
Dispensing ~ 100 today; 10,000 in ? years

50 year experience as a chemical

Safety Maintained

Goal
Summary

- The Hydrogen Delivery Infrastructure Has Evolved to Meet the Specific Needs of a Hydrogen Economy.
- Safety Risks Must Be Managed
  - Important Role of Good Engineering Design and Work Processes
  - Important Role of Codes and Standards
- Industry Stakeholders and The Public Must Gain Confidence That Hydrogen Supply, Delivery, Fueling, and Driving Are As Safe (or Safer) As Conventional Fuels
  - Achieve Thru Demonstrations
  - Improved Design to Make Differences Between Fuels Transparent
- Today’s petroleum fuel infrastructure was not built in a day….and doesn’t need to be replaced in a day! We are embarking on running a marathon and not a sprint.
Thank you

www.airproducts.com/h2energy