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%)
- Equipment and Energy (6%)
- Electronics and Performance Materials (21%)
- Healthcare (6%)
- Chemicals (9%)
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 85 hydrogen station projects
  - Exceeded 65,000 fuelings
  - in 12 countries
- Strong and broad IP position.
Emerging Hydrogen Economy Infrastructure Requirements

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

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

- **Delivery**
  - Distribution
  - Compression
  - Dispensing Systems
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-</td>
<td>Color</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>2-</td>
<td>Toxicity</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>3-</td>
<td>Odor</td>
<td>odorless</td>
<td>mercaptans</td>
</tr>
<tr>
<td>4-</td>
<td>Specific Gravity</td>
<td>0.07</td>
<td>0.424</td>
</tr>
<tr>
<td>5-</td>
<td>Environment - Leak</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Impact - Fuel</td>
<td>none</td>
<td>CO2 / NOx</td>
<td>CO2 / NOx</td>
</tr>
<tr>
<td>6-</td>
<td>Diffusion Coefficient (cm³/s)</td>
<td>0.61</td>
<td>0.15</td>
</tr>
<tr>
<td>7-</td>
<td>Flame Temperature (°C)</td>
<td>2318</td>
<td>2148</td>
</tr>
<tr>
<td>8-</td>
<td>Flammability Range (% in air)</td>
<td>4% - 75%</td>
<td>5.3% - 15%</td>
</tr>
<tr>
<td>9-</td>
<td>Ignition energy (milli Joules)</td>
<td>0.02</td>
<td>0.29</td>
</tr>
<tr>
<td>10-</td>
<td>Auto Ignition Temp. (°C)</td>
<td>520</td>
<td>&lt; 500*</td>
</tr>
<tr>
<td>11-</td>
<td>Heat Value (kJ/kg)</td>
<td>119,972</td>
<td>50,020</td>
</tr>
<tr>
<td>12-</td>
<td>Energy Density (MJ/Nm³)</td>
<td>10.783</td>
<td>35.882</td>
</tr>
</tbody>
</table>
Flammability Limits of H₂ Are Seven Times Wider Than CH₄
Overall Approach to Safety - Elements

- Inherently safe system design
  - Managing risks
  - Quantification of risks / risk analysis
  - Protective systems

- Safe operation of systems
  - Written procedures
  - Training and periodic retraining
  - Accident / near miss Investigation
  - Audits of training records
  - Periodic performance & leak checks of equipment
  - Personnel Protective Equipment - PPE
Hydrogen Sourcing

- **Central Production**
  - Hydrogen
  - Distribution
  - Fuel Station

- **Distributed Production**
  - Natural Gas, Propane, Methanol, Feedstocks
  - Distribution
  - Fuel Station
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.
Delivered Hydrogen

Gas Pipeline

Liquid Tank Trailer

Mobile Fueler

Gas Tube Trailer
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
Onsite Liquid Storage

- Stored at –423°F
- <150 psig.
- many sites

SS inner vessel
CS outer jacket
Insulation space
Proven technology
Underground Storage Tanks

- Direct buried
  - Inaccessible secondary containment
- Double walled design
- Nationally recognized codes
- 2 ft below surface
- Safety features
  - Relief & vent systems
  - Remote operated shut off valves
  - Corrosion control
Distributed H$_2$ Fueling Stations

Electrolyses

Steam Methane Reforming
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
Hydrogen Fuel Dispensing Stations
H₂ Impurities Sampled from All Stations – All Suppliers – All Supply Modes

- **Particulates**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

- **(N₂ + He + Ar)**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

- **NH₃**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

- **CO**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

- **CO₂**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

- **O₂**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

- **Total HC**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

- **H₂O**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

- **Total S**
  - Data Range
  - SAE J2719
  - Measured
  - Less Than or Equal To (Detection Limited)

*Calculated from SO₂, COS, H₂S, CS₂, and Methyl Mercaptan (CH₃SH).*
Alternate Applications build H₂ infrastructure

Off-road vehicles
H₂ Buses
HCNG Buses
Submarines
Cell-Towers
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®.

© Air Products and Chemicals, Inc. 2008
100 Years of Gasoline Fueling
Public Dispensing – 180,000

Safety Maintained

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

Goal

50 year experience
as a chemical
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