Hydrogen Infrastructure

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Agenda

- Who is Air Products?
- Hydrogen Infrastructure Today
- The Future of Hydrogen Infrastructure
- Key Messages
Air Products

Sales into Diverse Markets

- $10.4 billion company
- Diverse markets and geographies
- Positioned for continued long-term value creation

FY’08 Business Segment Sales

- Merchant (40%)
- Tonnage (35%)
- Electronics & Performance Materials (21%)
- Equipment & Energy (4%)

FY’08 Geographic Sales

- United States (41%)
- Europe (34%)
- Asia (18%)
- Canada/Latin America (5%)
- ROW (2%)
Leadership in Hydrogen Fuel Infrastructure

- Active since 1993
  - >90 hydrogen fueling projects
  - Stations installed in 15 countries
  - Have exceeded 78,000 Safe Fills

- Major role in hydrogen fuel safety codes and standards

- Broad technology base and intellectual property position

- Helping pave the way for a future hydrogen economy
Tonnage Gases
Market Leader in Refinery Hydrogen

Global #1 HyCO Position

On-stream 2007

APD
(1940 MMscfd)

Comp X
Comp Y
Comp Z

4,600 Million SCFD

H₂ Plant Operating Years

APD . . .
Widening Gap

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Hydrogen Facts

- AP total capacity could support 7-8 million vehicles if used only for vehicle fueling.
  - Excess capacity in CA and TX could support 100,000+ vehicles

- AP’s daily production equals:
  - 4.6 million kg/day
  - 1,316 liquid H2 trailers/day
  - 11,335 gaseous H2 tube trailers/day

- AP continues to build plants:
  - 2006, 6 plants, 450 MM scfd
  - 2008, 1 plant, 100 MM scf
    • 236,000 kg/day, 68 LHY trailers, 584 tube trailers

- Hydrogen is also used in glass, steel, foods, pharmaceuticals and electronics. We touch it everyday!
Hydrogen Production Methods

- Reforming – several types, different feed stocks
  - Central production or onsite generation
- Offgas/Waste stream clean-up
- Electrolysis
- Air Products operates all technologies
- Objective: Supply Customer with lowest cost molecule
Steam Methane Reformer

\[ \text{CH}_4 + 2 \text{H}_2\text{O} + \text{Heat} \rightarrow 4 \text{H}_2 + \text{CO}_2 \]
Industrial Gas Hydrogen Supply Integration

**HYDROCARBON FEED**
(CH4, C2, C3, C4, Naphtha, Offgas Fuel)

- SMR POX
- REFORMING
- PSA MEMBRANE
- PURIFICATION
- CRYOGENIC LIQUEFACTION
- LIQUID STORAGE

**STEAM / POWER**

**CUSTOMER(S)**

**GASEOUS PIPELINE**

**TUBE TRAILER**

**MERCHANT MARKET**

**CYLINDERS**

**CRYOGENIC TANKER**

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Hydrogen Pipelines Exist!

APD HyCO facilities
H₂ pipeline
CO pipeline
Syngas pipeline

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Delivered Hydrogen

- Liquid Tank Trailer
- Gas Pipeline
- Gas Cylinders
- Gas Tube Trailer
Waste Gas Clean-up

- Offgas of chemical plants have H₂
  - Chlor-alkali, ethylene, acetaldehyde, acetylene
- Offgas streams often vented or burned for fuel value
- Pressure Swing Adsorption used to produce H₂

PSA at Chlor-alkali plant (83,000 kg/day)
Simple System - Many Design Variables

PROCESS:
- Feed Pressure, Temp, Composition, Variability
- Product Purity Specs
- Off gas Pressure, Mixing Requirements
- H₂ Recovery
- Capacity, Turndown
- Reliability

DESIGN:
- Cycle Chart
- Number of Beds, Vessel Size
- Adsorbent Type & Split
- Number of Equalizations
- Purge Quantity
- Blowdown / Purge Split
- Feed & Purge G-rates
- Flow Distribution
Hydrocarbon Reforming – Onsite Generation

180,000 kg/day

100 kg/day
Onsite Reforming

- Fossil Fuel Feed Stock
- Various Technologies, SMR, ATR, POX
- 100 to 1000 kg /day
- Need to match supply with demand
  - Want high utilization to maximize efficiency
  - Excess supply results in venting or extra storage ($$$)
- Onsite Generation impacts downstream fueling station
  - Gaseous compression vs. liquid pumps (liquid more efficient)
  - Extra high pressure storage to minimize venting
  - Footprint of storage may be an issue
- Back-up system may be required for reliability
- Limited deployments to date. Technology, reliability and economics still being evaluated
Fuel Station Evolution – Onsite Generation

From This

To This
Electrolysis

- Limited deployment in North America
- Predominant to 300 nm3/hr in China
- Common in Latin and South America where bulk product is unavailable
- Common in the Middle East
- Strong Position throughout Asia
- 100 cc/min to 3000 nm3/hr systems
  - Larger systems are used to make ammonia and fertilizers
  - Hydropower typically used for large systems
  - Most systems are 10 nm3/hr-30 nm3/hr
  - Most electrolysis volume contributed by 5-10 huge systems
- Pathway to Renewables
Selection Criteria

- Capital Cost
- Operating Cost
- Cost of Hydrogen
- Hydrogen Requirement
  - Demand
  - Load Variation
  - Purity
  - Use Pattern
- Renewable
Hydrogen Fuel Infrastructure for the Future

- Turnkey Systems for safety
- Existing generation methods
  - Methane conversion technologies
  - Gas clean-up technologies
  - Gasification
  - Electrolysis
  - Renewables
- Need continued efforts in generation
  - Nuclear
  - Coal
- Supply of the most cost effective molecule to the marketplace may be regional

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Key Messages

- Hydrogen is here today. Thousands of customers purchase hydrogen via pipelines, trucks, cylinders and onsite generation.

- Air Products objective is to supply its customers with the lowest cost hydrogen molecule, regardless of the production and delivery method.

- A variety of factors are evaluated when determining the lowest cost supply of hydrogen to a customer.

- Hydrogen will likely come from a variety of feedstocks in the future, including cost competitive, renewable methods of production.
tell me more

www.airproducts.com/h2energy