Presentation Slides: Synergies in Natural Gas and Hydrogen Fuels

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SYNERGIES IN NATURAL GAS AND HYDROGEN FUELS

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Who Is Air Products?

- $9 Billion global company in atmospheric, process and specialty gases, performance materials, equipment and services provider
- Serving industrial, energy, technology and healthcare markets worldwide
- Fortune 500 company
- Operations in over 40 countries
- 18,300 employees worldwide
- Known for our innovative culture and operational excellence
- Recognized industry leader in safety
World’s Leader in Hydrogen

- World’s largest merchant supplier
- H₂ production equivalent to fueling ~8 Million cars/day
- Bulk, liquid and pipeline distribution
- More than 500 H₂ customers
- H₂ Energy projects since 1993
  - >130 hydrogen station projects
  - >350,000 fuellings/yr
- Parlayed MHE, cell tower, DOD experiences
- Stations in 19 countries
- Broad IP estate

Air Products’ Role in the LNG Industry

- World’s foremost provider of Natural Gas Liquefaction technology and Equipment
  - Full range of process options: from small plants to the world’s largest LNG process trains: 6 AP-X Units On-Stream in Qatar
  - Awarded equipment supply for the world’s 1st floating LNG (FLNG) project: Shell Prelude FLNG
  - Majority of the world’s LNG production employs Air Products’ processes and equipment (main cryogenic heat exchangers)
  - Main cryogenic heat exchangers manufactured by Air Products in the United States and exported worldwide
Natural Gas in US

2009 Consumption 22.71 Tcf
- Residential: 4.75
- Commercial: 3.11
- Industrial: 6.14
- Electricity Generators: 6.89
- Others: 1.42

AEO 2011 Reference Case 2025 Consumption 25.07 Tcf
- Residential: 5.02
- Commercial: 3.96
- Industrial: 8.1
- Electricity Generation: 6.66
- Others: 1.92

US Consumes ~3.2 Tcf of hydrogen annually

Industry
- Petroleum Refining: 67%
- Chemicals and Petrochemical: 31%
- Metals: 1%
- Other: 0.5%

Refining Hydrogen and Energy Driving Hydrogen Growth
- Outsourcing 15%
- Crude: 15%
- Conversion: 4%
- Clean fuels: 15%
- More heavy, sour crude
- Increased outsourcing trend

Source: SRI Consulting 2010 Chemical Economics Handbook
Natural Gas Pathways Into Transportation

Energy Source: Natural Gas
Conversion Alternative: Liquefaction, Gas-to-Liquids, Power, Reforming
Transportation Fuel: CNG, LNG, Diesel, EV/PHEV, Hydrogen

Transportation Energy Price Projections (EIA Reference Case)

1. Sales-weighted average price for all grades. Includes federal, state, and local taxes.
2. Motor fuel for clean-up case includes federal and state taxes while excluding county and local taxes.
3. Compressed natural gas used as a vehicle fuel. Includes estimated motor vehicle fuel taxes and estimated dispensing costs or charges.

Source: DOE EIA Annual Energy Outlook 2011 With Projections to 2035.
Hydrogen Feedstock Evolution

- Nuclear Electrolysis
- Thermal
- Renewable Sources - Electrolysis
- Hydropower, Wind, Solar, Geothermal
- Renewable Sources - Reforming
- Biomass
- Carbon Sources
- Natural Gas - SMR
- Clean Coal
- Existing H₂ Sources
- Refineries
- Chlor-Alkali Plants

- Hydrogen from natural gas is today’s starting point
- Biomass is first logical step for large-scale renewable hydrogen
- Hydrogen from renewable electricity is regional / long-term

Years After Mass Market Commercialization Effort Starts

Renewable Hydrogen Potential

- Theoretical Potential
- 395 Million H₂ cars
- 21 Billion H₂ cars
- 1,251 Million H₂ cars
- 270 Million H₂ cars

- Solar PV/CSP
- Wind
- Geothermal

Source: Air Products and Chemicals, Inc. - 2011
### Significant GHG Reduction with Today’s Supply

**Well-to-Wheels Greenhouse Gas Emissions**

*direct emissions, based on a projected state of the technologies in 2020*

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>CO₂-equivalent per mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>350</td>
</tr>
<tr>
<td>Hybrid Electric</td>
<td>100</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td>40</td>
</tr>
</tbody>
</table>

**Hydrogen Supply**

- H₂ from Nuclear High-Temp Electrolysis: 80
- H₂ from Central Wind Electrolysis: 80
- H₂ from Biomass Gasification: 40
- H₂ from Coal with Sequestration: 16
- H₂ from Distributed Natural Gas: 20

**Total CO₂-equivalent per mile:**
- 350 (Conventional)
- 100 (Hybrid Electric)
- 40 (Fuel Cell)

*All emissions from these pathways will be lower if these figures are adjusted to include:
- The displacement of emissions from grid-power generation that will occur when surplus electricity is co-produced with cellulosic ethanol
- The displacement of emissions from grid-power generation that may occur if electricity is by-produced with hydrogen in the biomass and coal pathways, and if surplus wind power is utilized in the wind-to-hydrogen pathway
- Capture disposal sequestration in the steam-methanation process*

Adapted from DOD hydrogen program record #9002.

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### CNG/LNG Supply Chain

1. **Feedstock**
   - Conventional NG
   - Unconventional NG, Bio-methane

2. **Liquefaction**

3. **LNG Distribution**

4. **LNG Station**

5. **Transmission (Pipeline)**

6. **Compression**

7. **Distribution System**

8. **CNG Station**

9. **LD Vehicles**
10. **CNG**
11. **MD Trucks/Buses**
12. **HD Trucks**
13. **LNG**
14. **LNG Station**
15. **Locomotives/Marine HHP**
Hydrogen Supply Chain Options

- H2 Compression
- LH2 Formation
- LH2 Distribution
- LH2 Storage
- Distributed LH2 Production
- H2 Stations
- Feedstock
  - Natural Gas
  - Bio-methane
- Central SRM
- H2 Liquefaction
- LH2 Distribution
- LH2 Storage
- Distributed LH2 Production
- Solar or Wind
  - Energy
  - Electrolysis

Codes & Standards

**Importance of Codes & Standards**

- Improves Safety
  - Paramount importance to all
- Provides Education to AHJ
  - Example: CGA pamphlets
- Provides Consistency
- Assists with Permitting
  - Appropriate C&S help AHJ’s make decisions
- Helps with legal issues
- Levels playing field for all participants

**Progress in Codes and Standards Development**

- It’s frequently said “There are no Codes and Standards for Hydrogen Fueling”.
- This is not the case.
- In fact, there are so many, we can’t cover them all here today
- Industrial Codes and Standards
  - Adopted by reference
- Specific Fuel Station Codes and Standards
  - NFPA
  - I-Codes
  - SAE J2719
  - SAE J2601
Summary

- US has an abundant amount of natural gas that’s expect to be developed at low cost
- The substantially lower carbon footprint for natural gas and hydrogen produced from natural gas makes natural gas a bridge to a low carbon future
- US renewable energy supply is also abundant and important in developing the long-term solution
- Natural Gas and Hydrogen supply chain infrastructure continue to lower cost and expand in targeted markets
- End market Total Cost of Ownership of vehicle and fuel will influence market acceptance and market scale of alternative fuels

Thank You!
www.airproducts.com/h2energy

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