

A group of children are shown from an overhead perspective, holding a globe of the Earth. They are arranged in a circle, with their hands resting on the globe. The children are wearing colorful clothing, and the background is a light blue color. The overall image has a soft, ethereal quality.

Hydrogen Delivery/Safety

Air Products and Chemicals, Inc.

B. B. Bonner

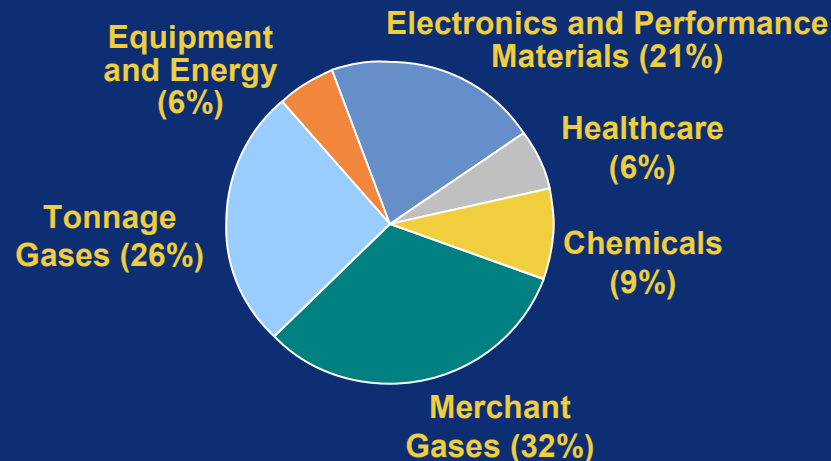
The American Ceramic Society and ASM International Conference
Material Innovations in an Emerging Hydrogen Economy

25 February 2008

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

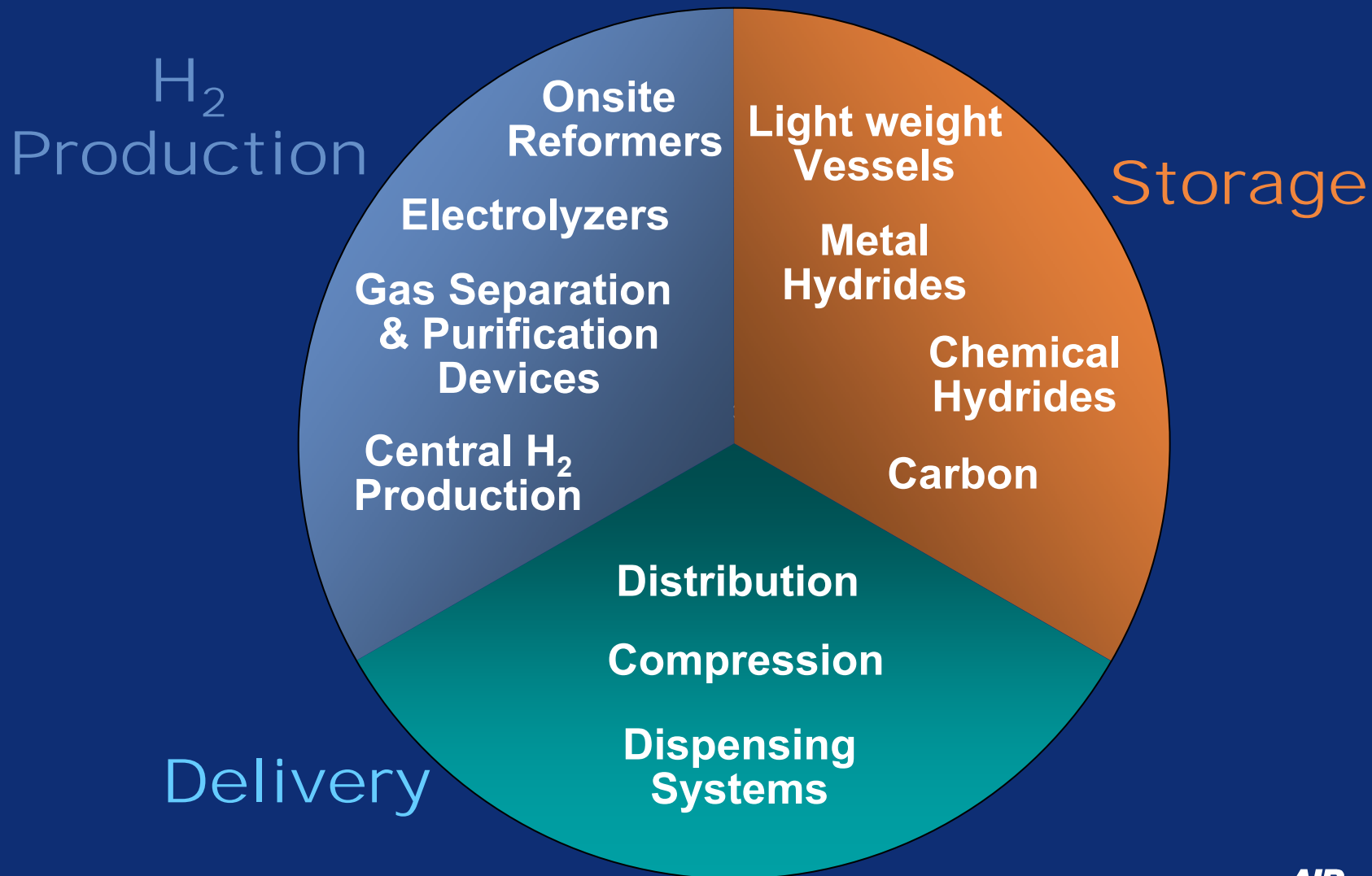


Leadership in Hydrogen Fuel Infrastructure

- **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



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

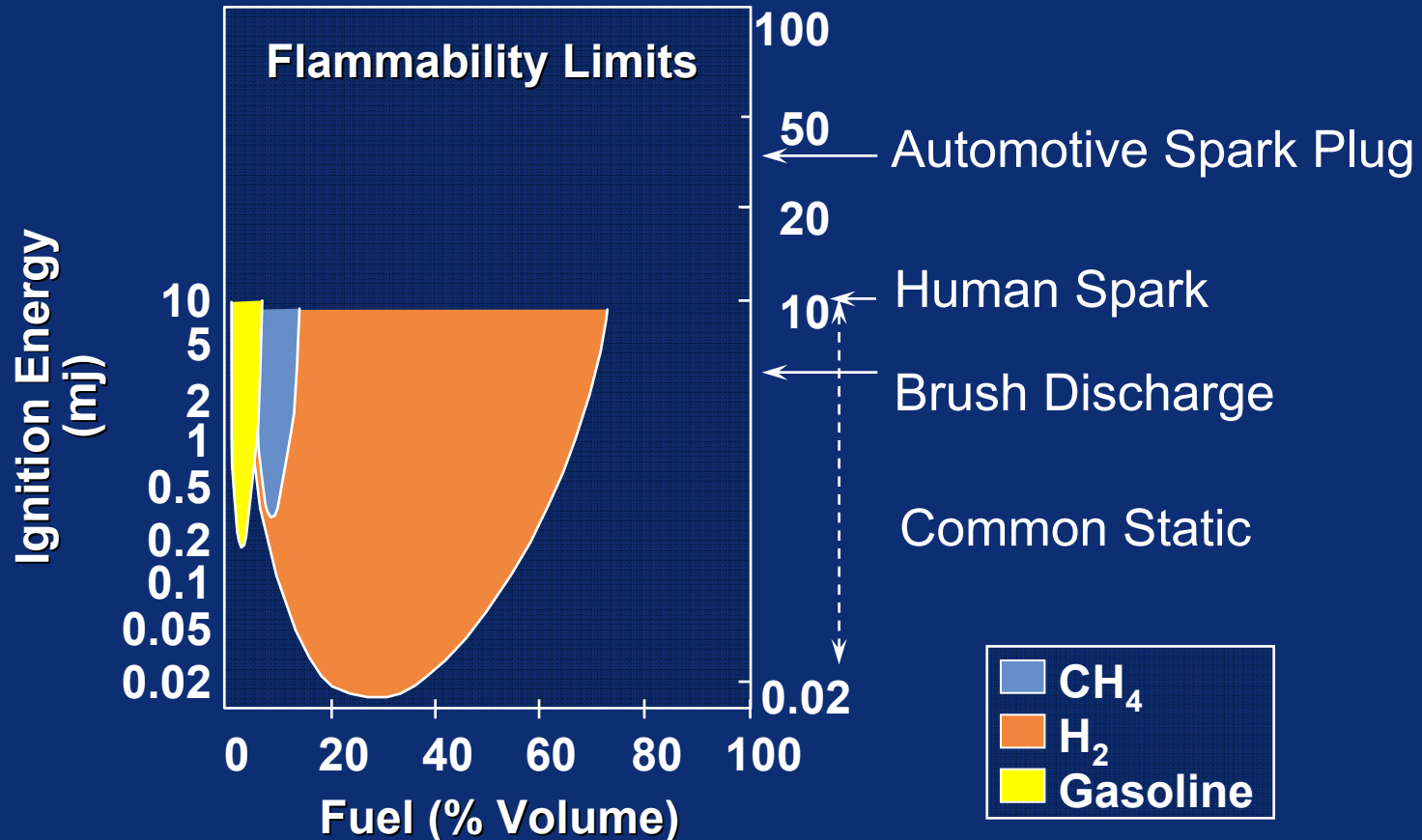
18.3 – 59% by vol. in air

- **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

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

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



Mobile Fueler

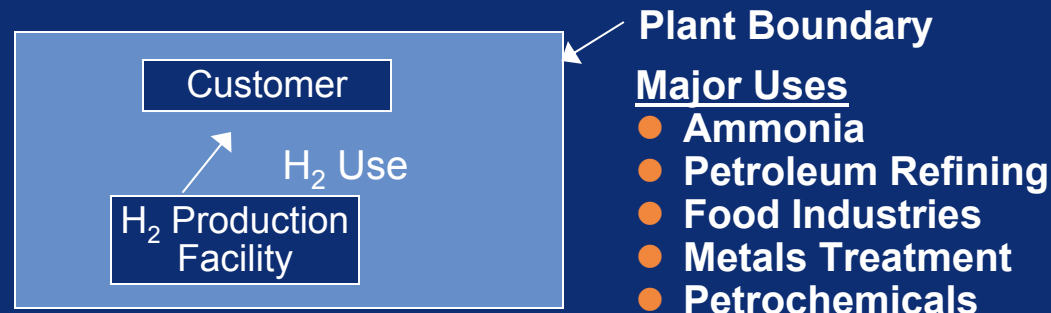


Gas Tube Trailer

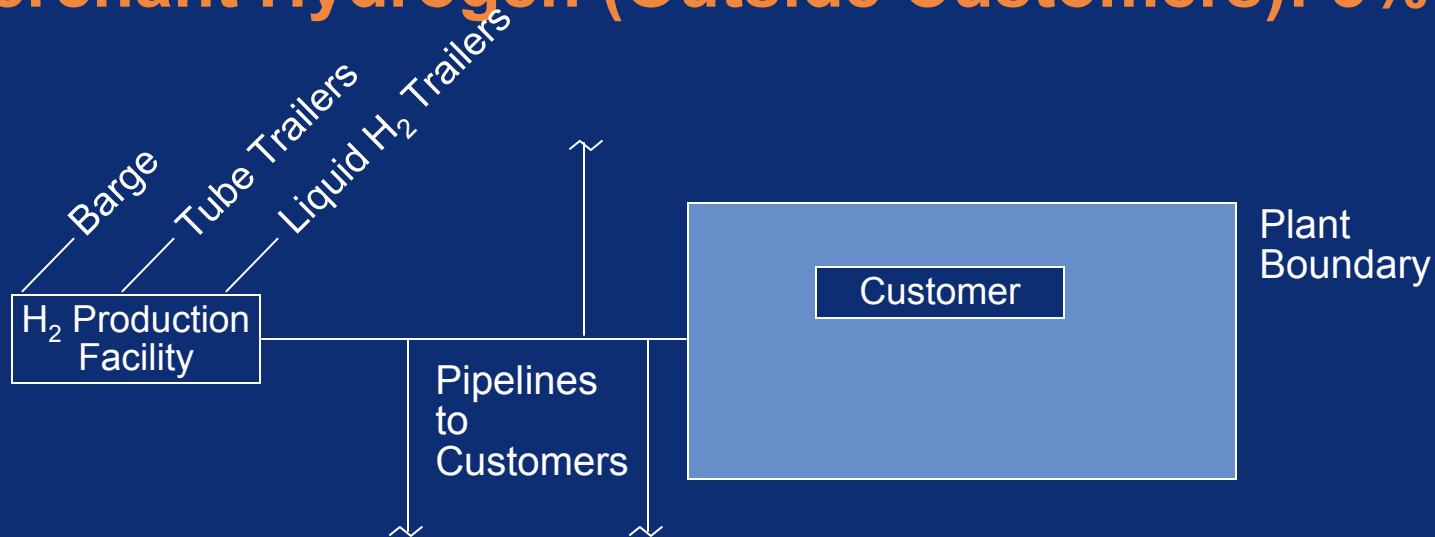


Total U.S. Hydrogen Production: Approx. 30 Billion SCFD

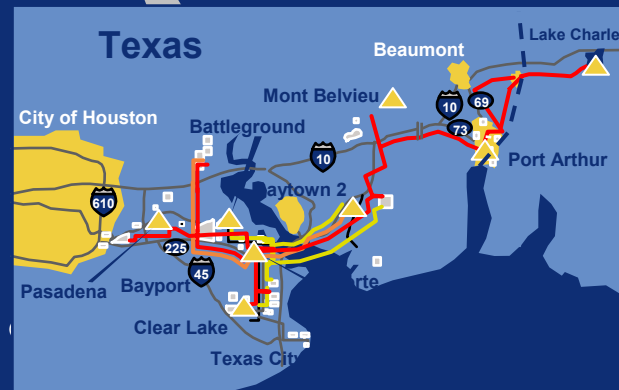
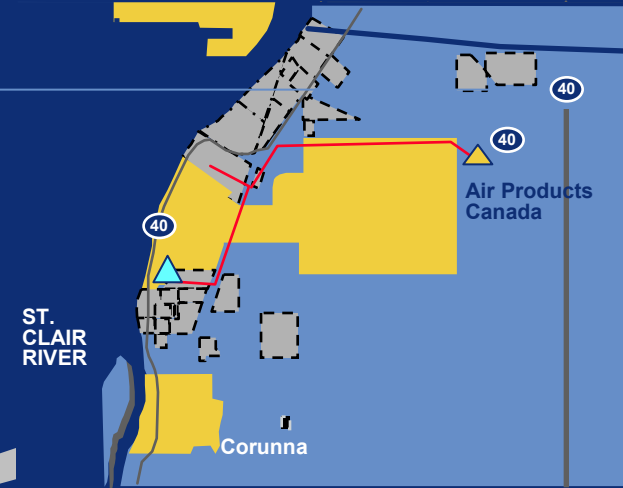
Hydrogen Consumed Where Produced: 97%



Merchant Hydrogen (Outside Customers): 3%



Hydrogen Pipeline Positions



- ▲ APD HyCO facilities
- H₂ pipeline
- CO pipeline
- Syngas pipeline

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



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

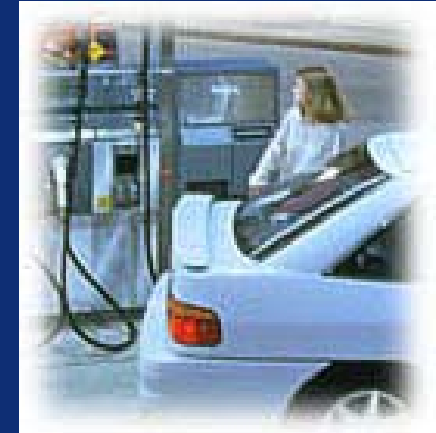
- **Improves Safety**
 - **Paramount importance to all**
- **Provides Education to AHJ (Authority Having Jurisdiction), such as CGA or NFPA pamphlets**
- **Provides Consistency**
- **Assists with Permitting, as helps AHJ's make decisions**
- **Levels playing field for all participants**
- **Key to long-term 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



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