Hydrogen Delivery/Safety

Air Products and Chemicals, Inc.

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

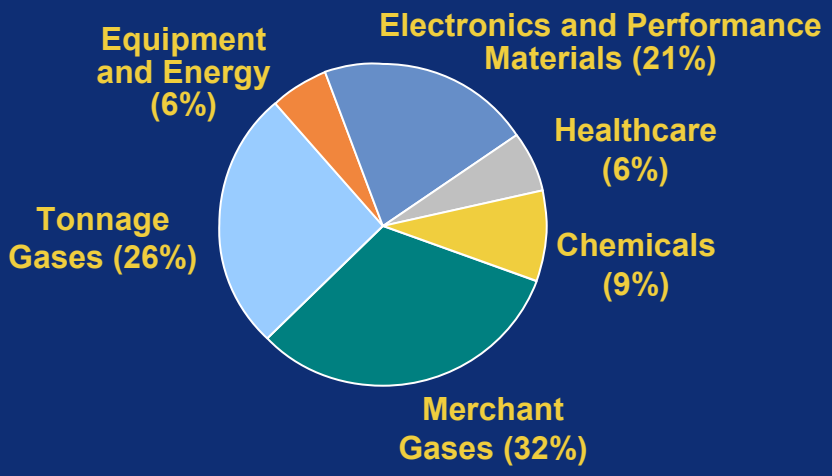
25 February 2008

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

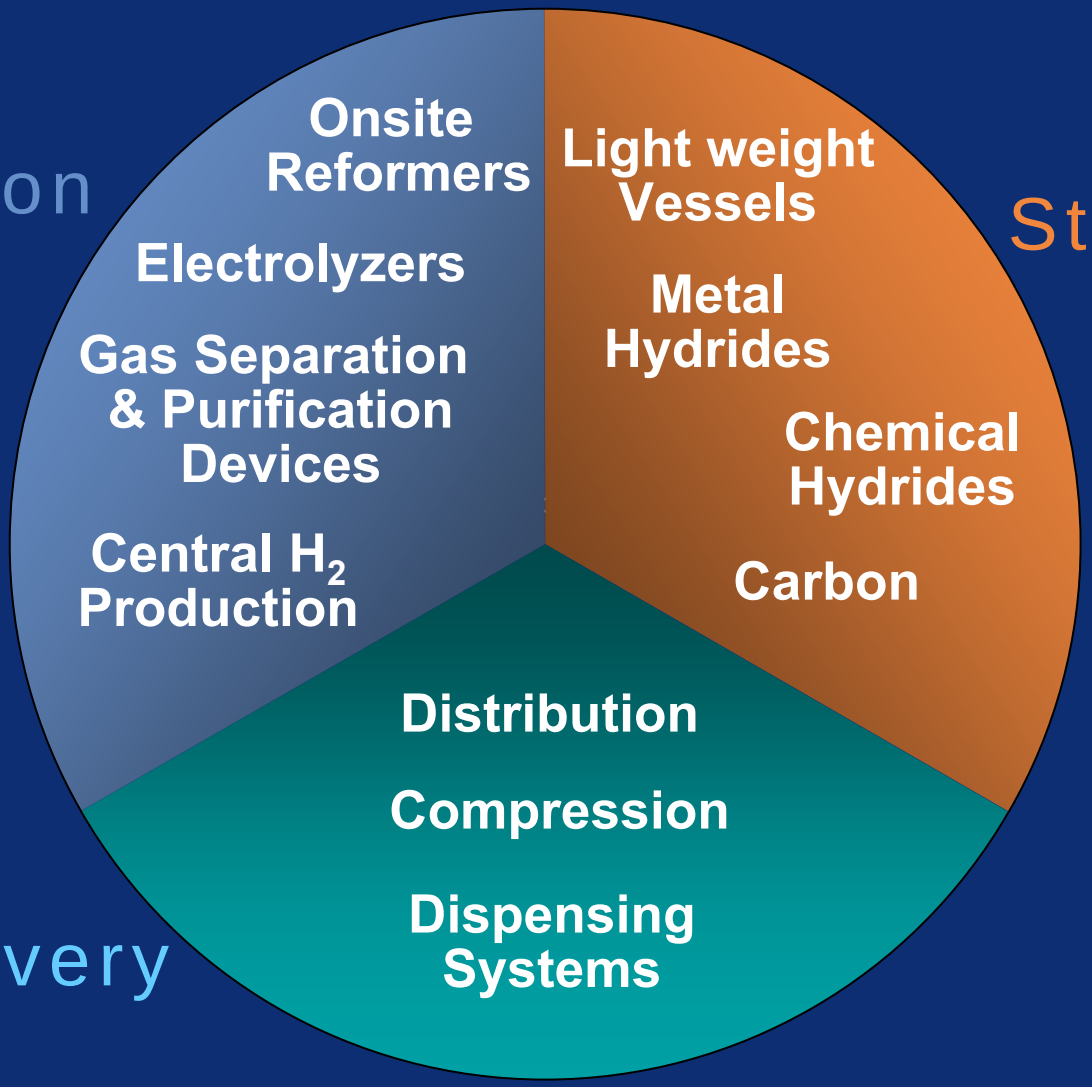
By Reporting Segment



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



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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

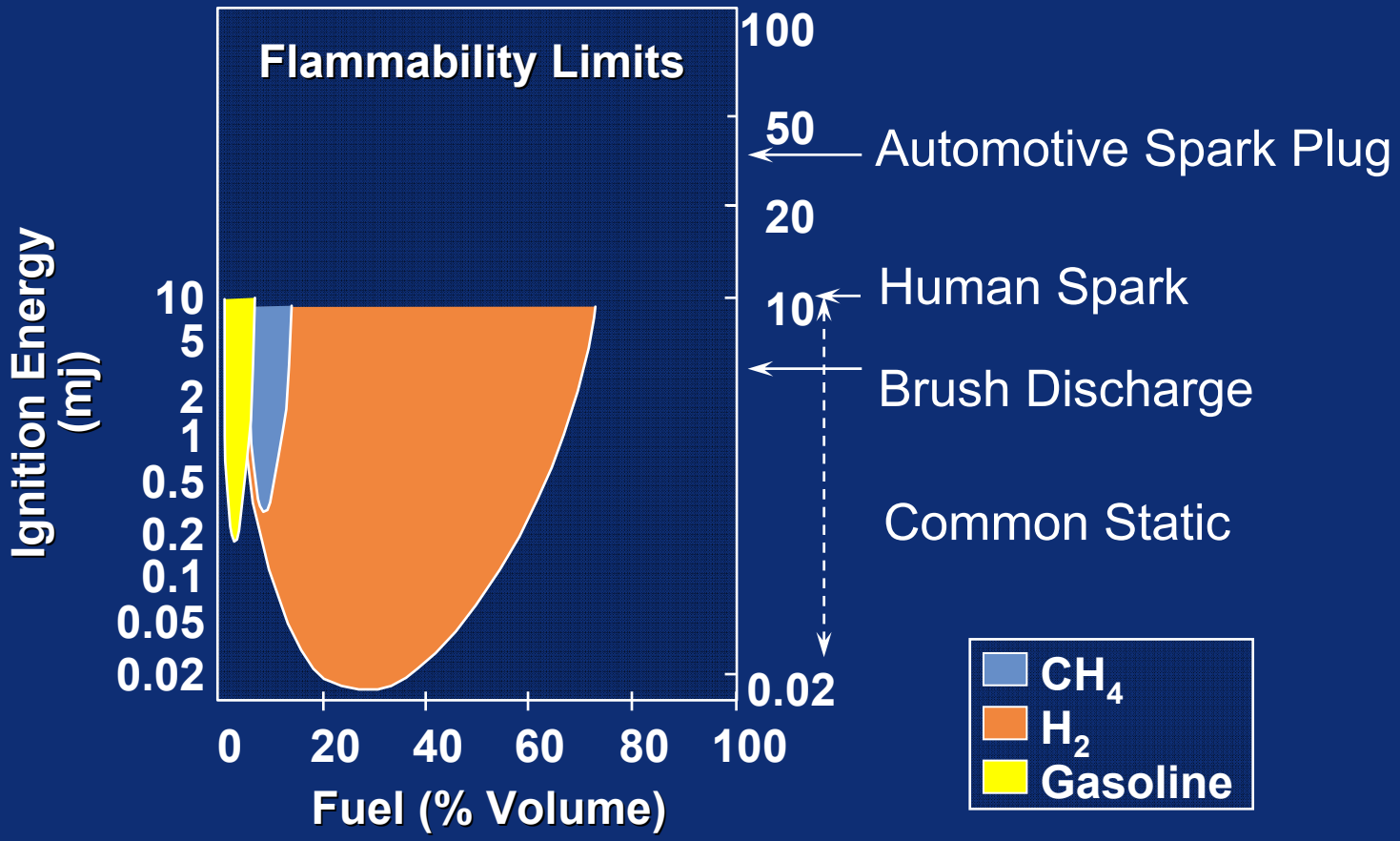
Flammable Range	**4 - 74% by vol. in air**
Detonable Range	**18.3 – 59% by vol. in air**

- **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

		H2	NG	Gasoline
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-	Flammablility 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 H_2, CH_4 and Gasoline with Air



Flammability Limits of H_2 Are Seven Times Wider Than CH_4

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Delivered Hydrogen

Gas Pipeline

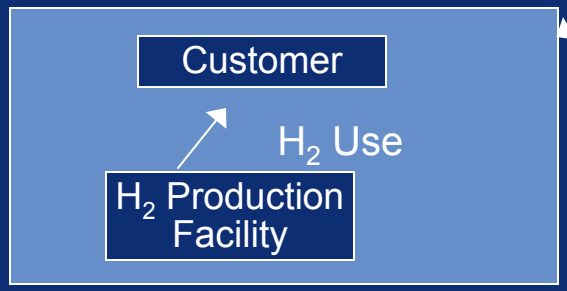
Liquid Tank Trailer

Gas Tube Trailer

Mobile Fueler

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

Hydrogen Consumed Where Produced: 97%

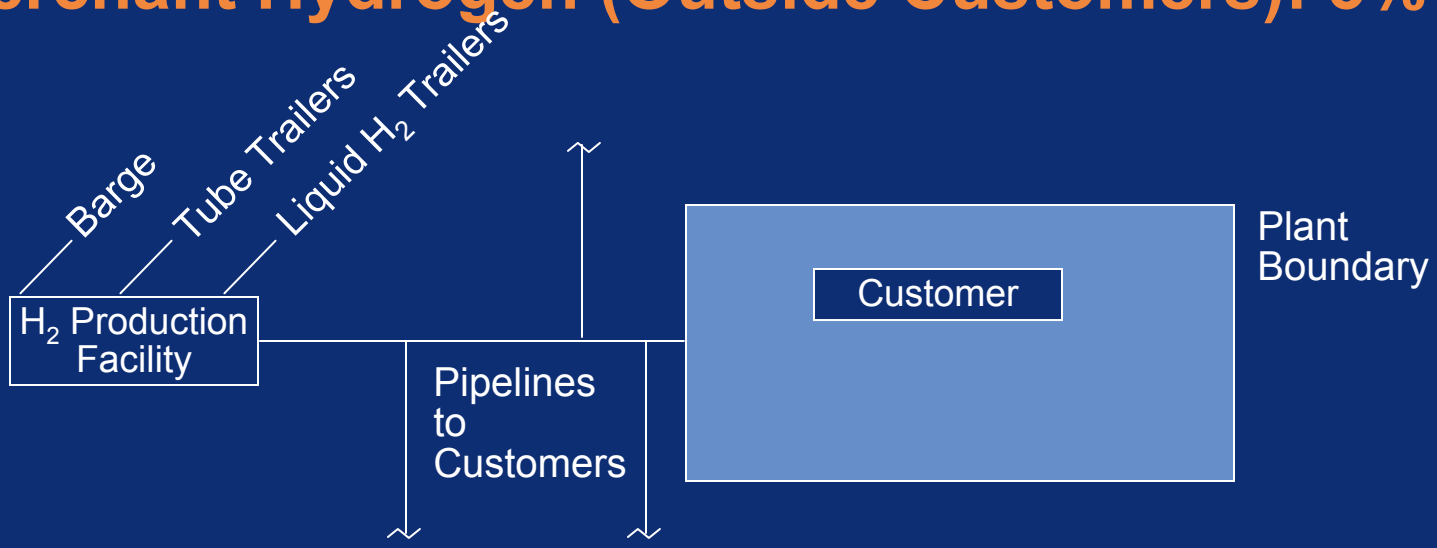


Plant Boundary

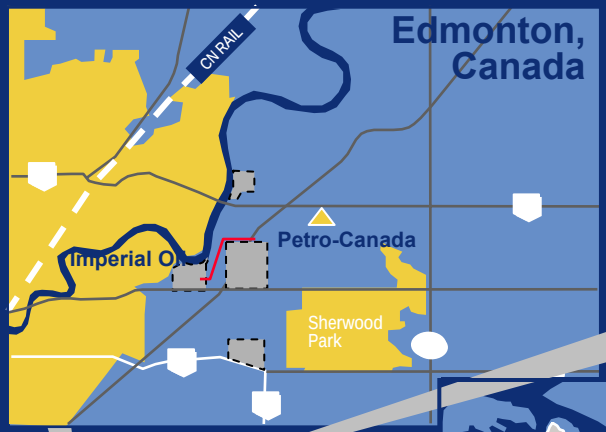
Major Uses

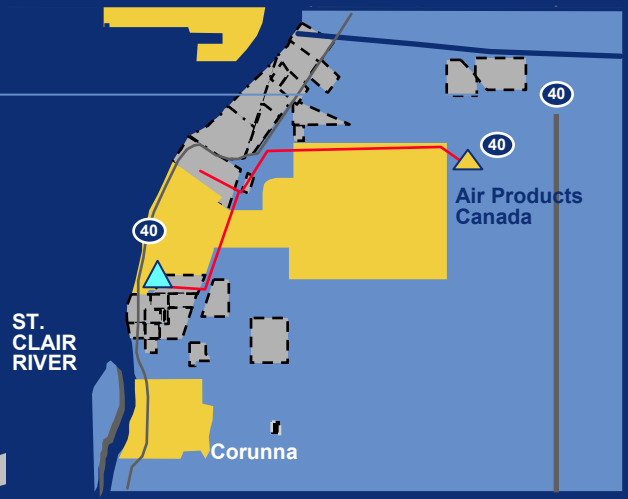
- **Ammonia**
- **Petroleum Refining**
- **Food Industries**
- **Metals Treatment**
- **Petrochemicals**

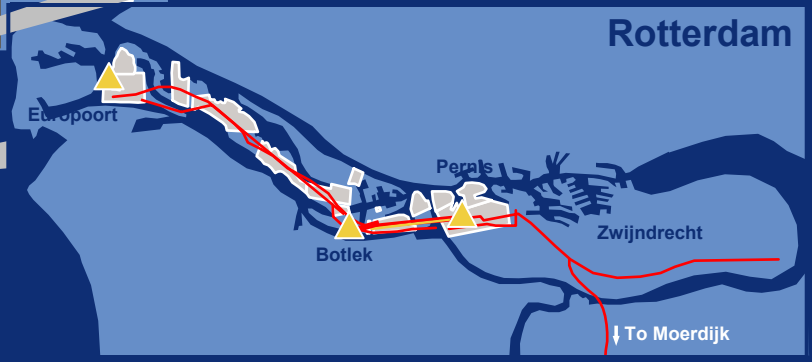
Merchant Hydrogen (Outside Customers): 3%

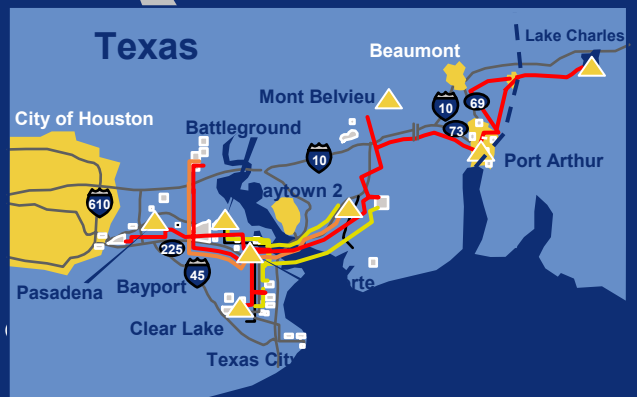


Hydrogen Pipeline Positions









- APD HyCO facilities
- H_2 pipeline
- CO pipeline
- Syngas pipeline

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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**

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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 H_2 Over 25 Year Period Without a Significant Incident**
- **Vehicle Accidents Do Occur**

Hydrogen Distribution

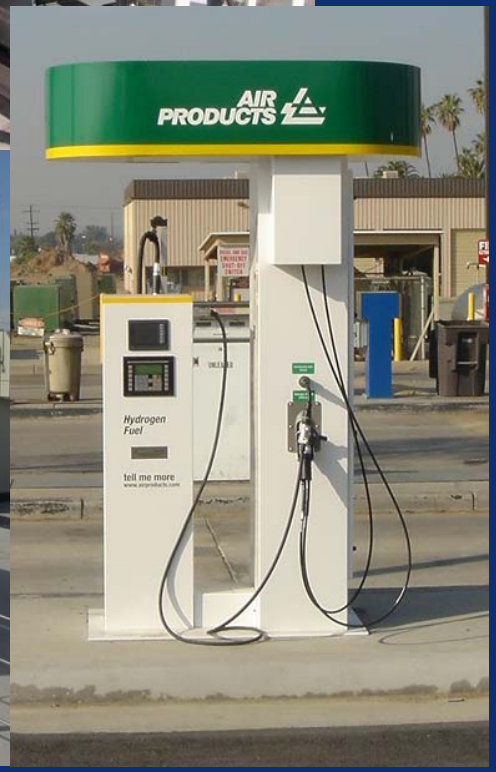
Truck in *gaseous* hydrogen

- **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.**

H_2 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, KnowH_2ow®.**

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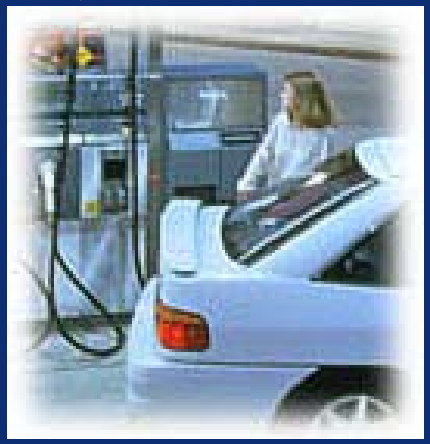
100 Years of Gasoline Fueling

Public Dispensing – 180,000

Safety Maintained



Hydrogen Fueling in Infancy

Dispensing ~ 100 today; 10,000 in ? years

Goal

50 year experience

as a chemical

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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