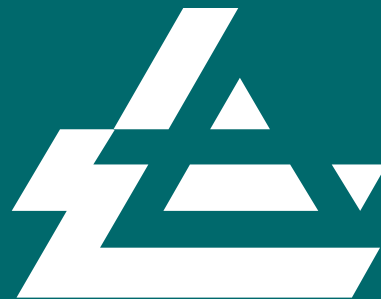


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Presented by Robert N. Miller of Air Products and Chemicals, Inc. at the West Virginia Hydrogen Workshop on November 19, 2003 at Stonewall Resort, Roanoke, WV. This meeting was a part of the Energy Roadmap Workshop Series commissioned by West Virginia Governor Bob Wise.

AIR
PRODUCTS



A group of diverse children are shown from a high angle, holding a globe of the Earth. They are all smiling and looking towards the camera. The background is a soft, light blue. The text is overlaid on this image.

Fueling a Cleaner Future with Hydrogen

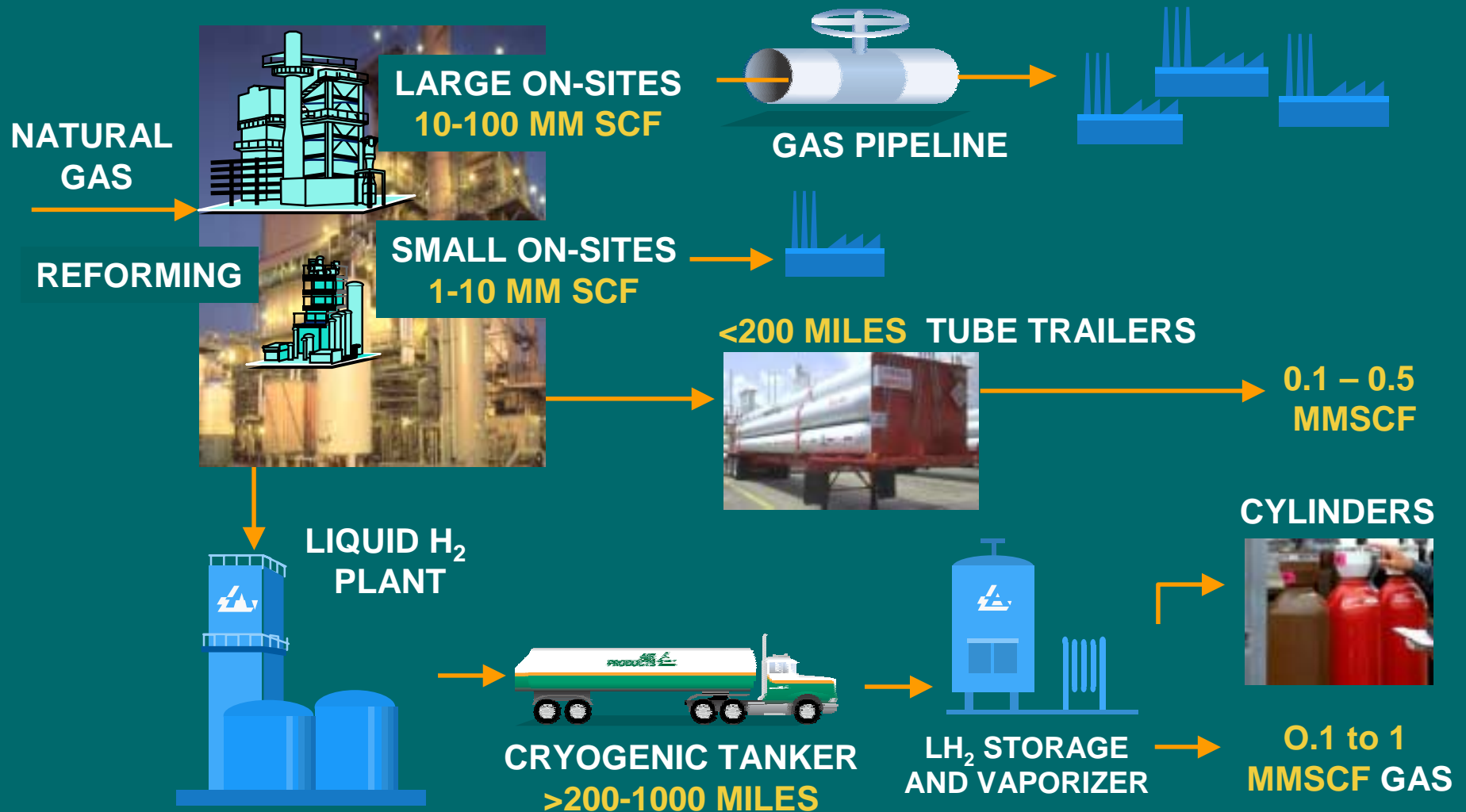
Robert N. Miller
Corporate Technology
Air Products and Chemicals, Inc.
19 November 2003

Distributing Hydrogen

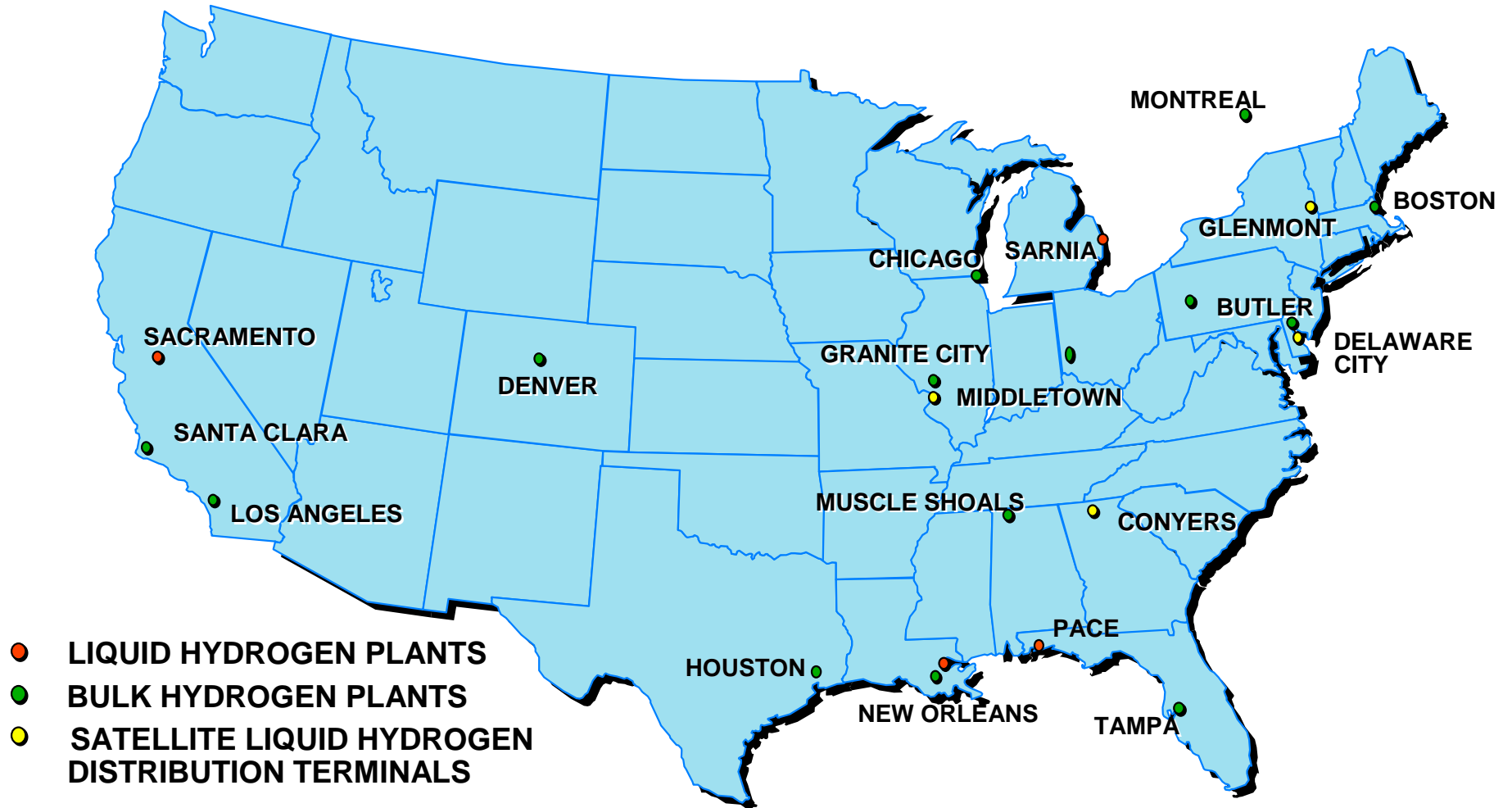
- Today's Infrastructure
- Emerging Concepts
- Hydrogen Economy Vision

Merchant Hydrogen Business

Supply Tailored to Customer Need



Liquid and Bulk Hydrogen Plants and Distribution Terminals: USA



Liquid Hydrogen Infrastructure

- **Hydrogen liquefied for cost-effective transport and storage**

- High density; low boil-off
- Ultra High purity 99.995%



- **Extensive distribution infrastructure in US**

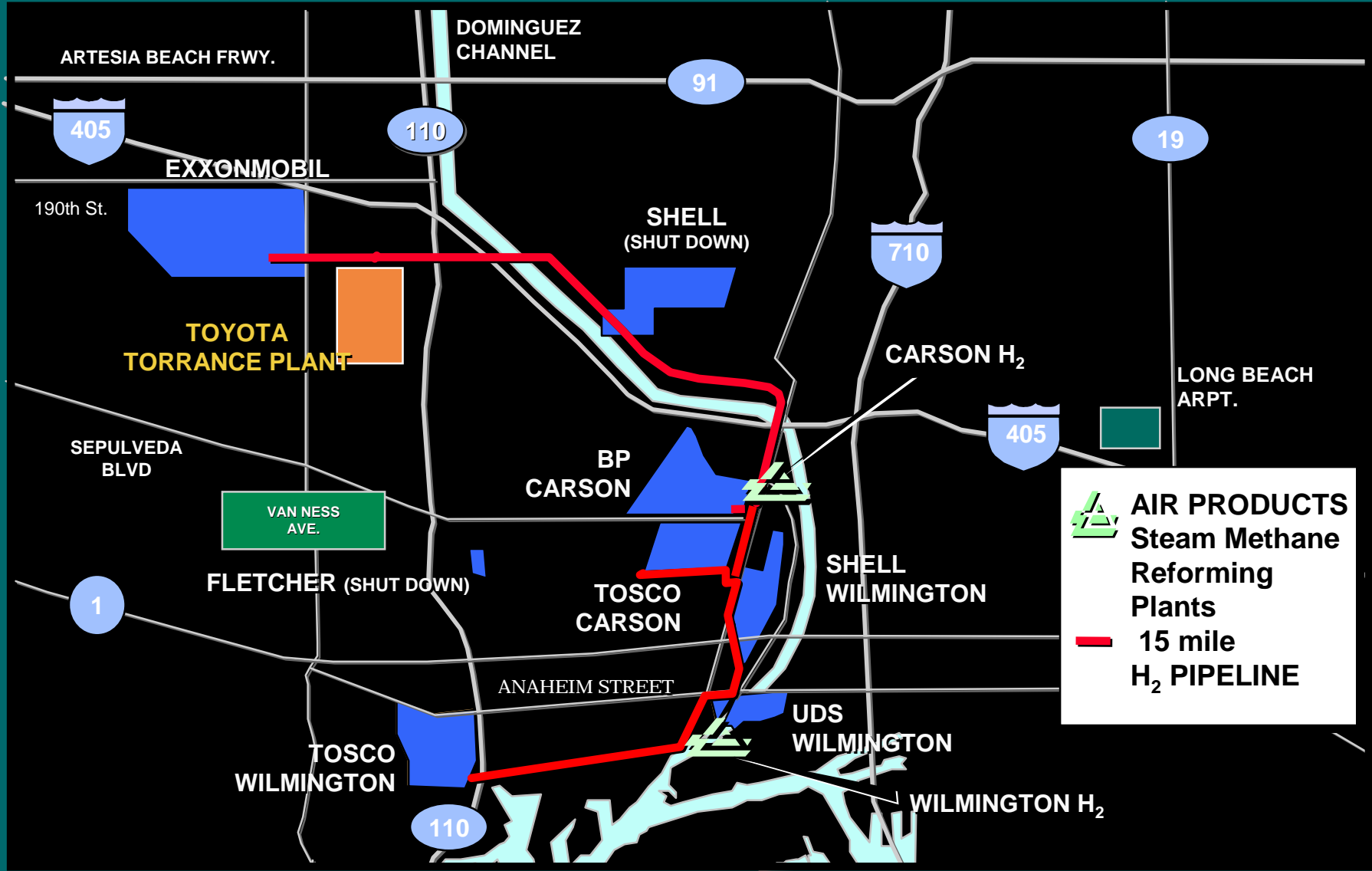
- Delivery by 15,000 gallon tankers – Up to 3,300 kg H₂
- Driven safely over 11,000,000 miles per year
- Delivery every 30 min. nationwide
- Total US capacity = 212 TPD ~ = 100,000 fills ~ = 700,000 vehicles

Air Products Hydrogen Pipelines Serving The World

Over 1 Billion SCFD Capacity



Urban Los Angeles H₂ Pipeline



Relative Economics* of Central vs Local H₂ Production by SMR from Nat. Gas

Scenario A (150 TPD)

Scenario B (0.3 TPD)

\$/kg **	Liquid H ₂	Pipeline	Tube Trailer	\$/kg
Production	2.21	1.00	1.30	
Delivery	0.18	2.94	2.09	
Fueling	1.27	1.07	1.00	
Total	3.66	5.00	4.39	4.40

**** The H₂ Cost in \$/Kg is approximately equivalent to \$/gallon gasoline**

While the cost of H₂ as produced at a large plant seems attractive (\$1.00/Kg), at the filling station the transport and fuelling expenses predominate, rendering local” H₂ production at least comparable.

*From “Hydrogen Supply: Cost Estimate for Hydrogen Pathways – Scoping Analysis”
D. R. Simbeck, E. Chang, SFA Pacific, Inc. NREL NREL/SR-540-32525, July 2002

Infrastructure overview

Today

Hydrocarbon sourced infrastructure exists

- Global production: 45 billion kg/yr
- Industrial applications: chemicals, metals, electronics, space
- 95% of H₂ used captively



PATHWAY ?

Tomorrow
Renewable sourced H₂ for transportation and energy storage for power generation



Vision of H₂ Infrastructure Growth

- **Early stages:**
 - Delivered H₂ – Rely on existing industrial H₂ infrastructure
 - “Micro” on-site reformers
 - Electrolysis of water
- **Build-out distributed H₂ generation using natural gas network**
 - In-step with growth in demand
- **Introduce renewable, coal and nuclear hydrogen opportunistically and as economics improve**



Hydrogen Infrastructure Rollout

Key Factors

1. Regional dynamics and geographic constraints
2. Distance from production to point of use
3. Capital utilization

Infrastructure Solutions will include:

1. Leveraging existing infrastructure
2. Point of use generation
3. Combined fueling and energy
4. Hydrogen feedstock flexibility
5. Pipeline installation and conversion

Early Adopters will be:

Demonstrations, pre-production vehicles, fleets

Early Hydrogen Fuel Stations

- **Hydrogen Fuel Station**

- Sized for delivery of 2, 20, 200 or 2000 kg/day servicing 4, 40, 400 or 4000 vehicles.
- Consists of fuel source, compression, storage & dispenser.
- Hydrogen Generation by SMR or Electrolysis

Low Cost Fueling Options Series-100 Station *(20 kg/d serves ~ 100 vehicles)*



Emerging FCV Fleets Series 200 *(50 kg/d serves ~ 250 vehicles)*



Relocatable and Portable Hydrogen Fuelers

- **Totally self-contained**
- **No site installation**
- **High reliability**
- **Zero emissions**
- **75 - 150 kg H₂ (~100 to 200 vehicles)**



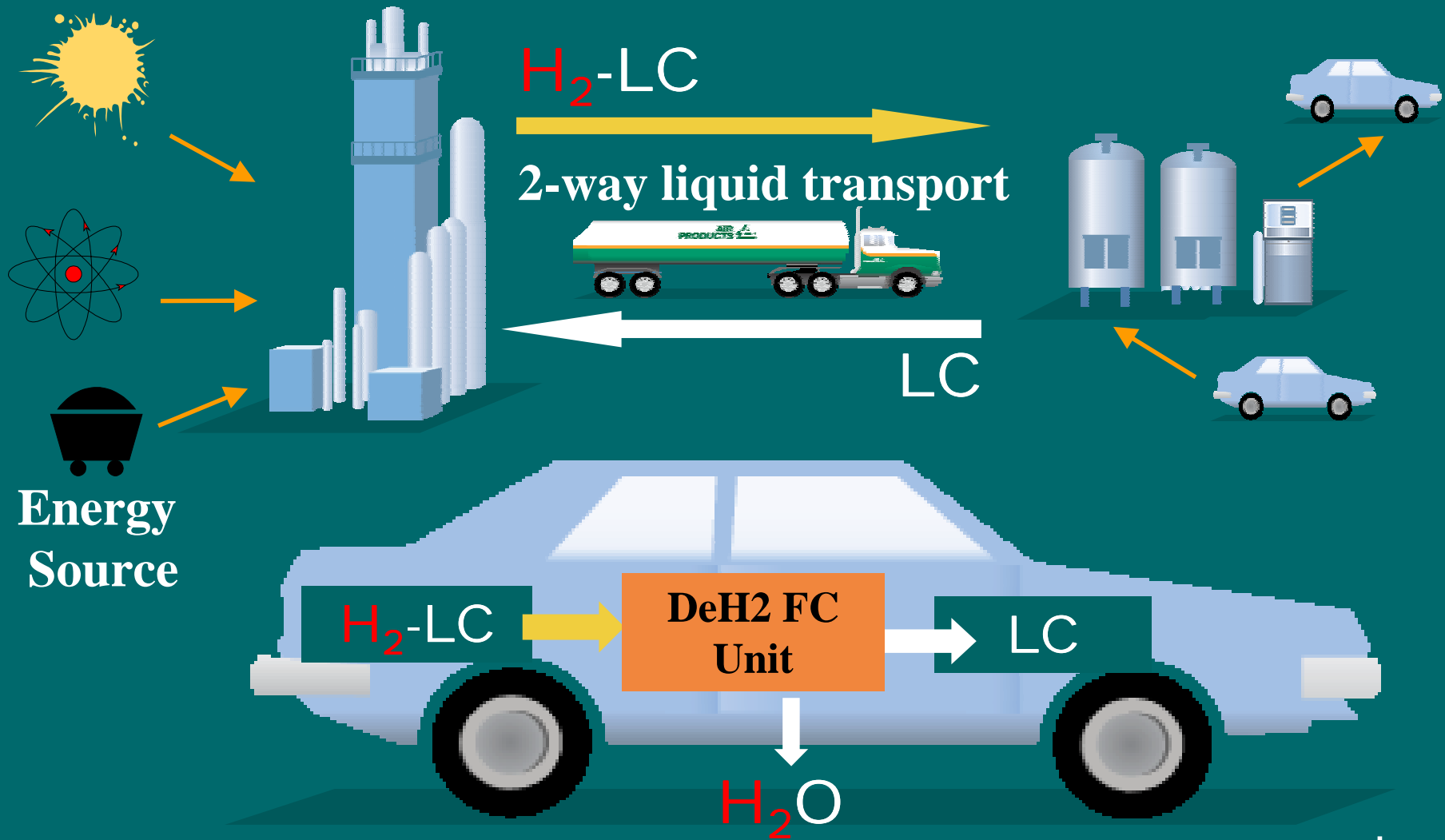
Distributed Hydrogen Networks for Stationary Power

- Fuel Cell installation on existing H₂ pipelines
- Using Current small H₂ on-site plants (> 1 MW)
- Adding small onsite H₂ generators -- ~ 50 kW
- Energy Station - Co-production of H₂ fuel and power.
- H₂ Power Park - Central H₂ production serving a concentrated cluster of fuel cell users



A Future Distribution Scenario

a Reversible "Liquid Hydride" using existing liquid fuel infrastructure



Summary

- **Hydrogen is available now**
- **There will not be a single pathway solution**
 - **Based on application needs and locations**
- **Long-term, lowest-cost solution still being developed**
 - **Depends on the ultimate fuel cell, vehicle and device needs**

Thank you