H2@Scale

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GLOBAL MARKETS
& TECHNOLOGIES

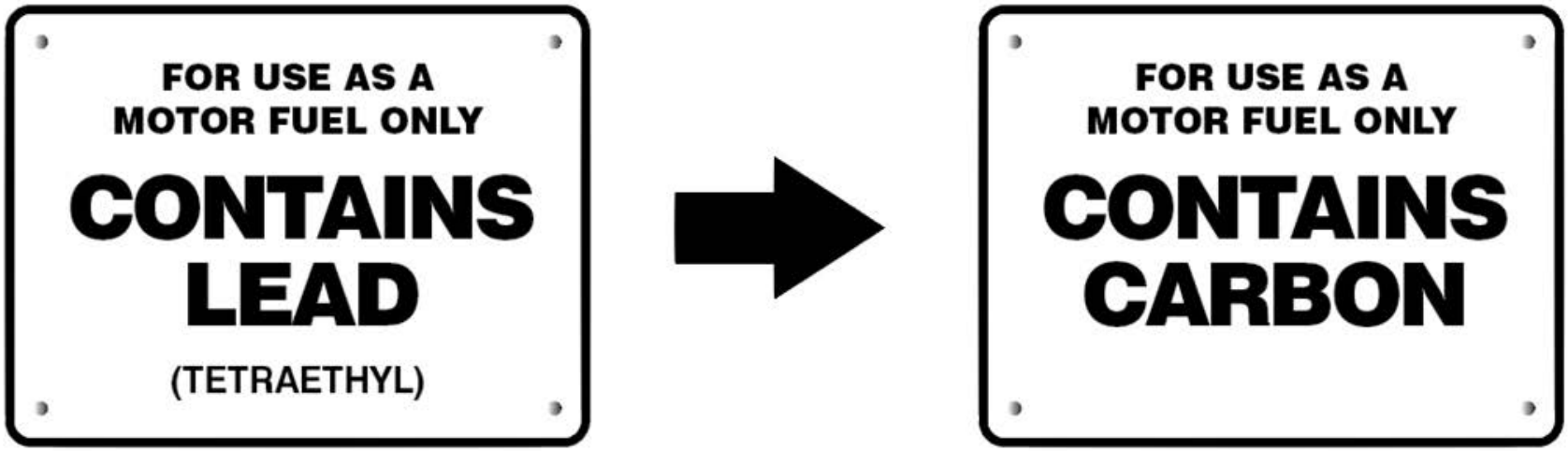
Who is Air Liquide?

67,000 employees in 80 countries
We now serve over 3 million customers and patients
40% of the Group revenue is linked to protecting life and the environment
In 2016, the Group revenue was $19 B with net profit of $1.9 B

433 plants worldwide (ASU, SMR, Cogeneration)
A pipeline network that spans over 9,000 km
12,000 trucks
24 million cylinders

€288 million of expenses dedicated to innovation in 2016
60% of these expenses are related to projects that help to protect life and the environment
Around 300 patents registered each year
9 research centers located though out the world (Europe, Asia and the United States)
6,200 employees of the Group contribute to innovation
The Group invested in 27 start-ups through its venture capital arm ALIAD

Changing Transportation Fuel “@Scale” is possible



How to Measure it?

Metric Tons (Ton)
Metric Tons Per Day (TPD)

Production:
Electrolyzer: 1.5-65 TPD (3-135MW)
SMR: 20 - 400 TPD

Storage (Capacitance):
Liquifier: 10-30 TPD
Liquid Tank: 4 - 200 Ton
Gaseous Salt Cavern: 5000 Ton
Gaseous Pipeline: 5 Ton/mile*

Distribution:
Gaseous Tube Trailer: 0.3 - 1.3 Ton
Liquid Tanker: 2-3 Ton
Gaseous Pipeline: 5 Ton/mile*

HISTORICAL LARGE SCALE PLANTS

Rjukan, Norway; 1927 – 1970's

Glomfjord, Norway; 1953 – 1991

- Two largest electrolyser plants worldwide
- Capacity: 30 000 Nm^3/h each
- Energy consumption: approximately 135 MW each
- Supplied by renewable hydro power

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NEL HYDROGEN

http://www.sintef.no/contentassets/9b9c7b67d0dc4fbf9442143f1c52393c/9-hydrogen-production-in-large-scale-henning-g.-langas-nel-hydrogen.pdf

*Speculative - value needs verification meant only for scale comparison

Industrial Scale

US Hydrogen Production:
27000 TPD (DOE Estimate)

Miles of Pipeline:
1600 mi pipeline (DOE Estimate)

Total US Storage (pipeline and caverns): 15000-20000 Tons*

<u>Goal #1 - Stabilizing New Carbon Emissions:</u>

Hydrogen from Biogas resources: 2000 TPD (654 Bscf/yr of biogas USDA Biogas Oppts Roadmap)

- **Less than 10% of production capacity- limited SMR development**
- **100 new 20 TPD liquifiers**
- **2000 TPD hydrogen stations (around 20,000 stations of current size)**
- **1300-5000 Tube Trailers or 650 LH2 Tankers**
- **3.6 Million FCEV**

*Speculative - value needs verification meant only for scale comparison

Industrial Scale

Goal #2 - Reduce Net Carbon Emissions:

Hydrogen from Biogas resources with CCS

Cost & Scale Competitive Electrolysis

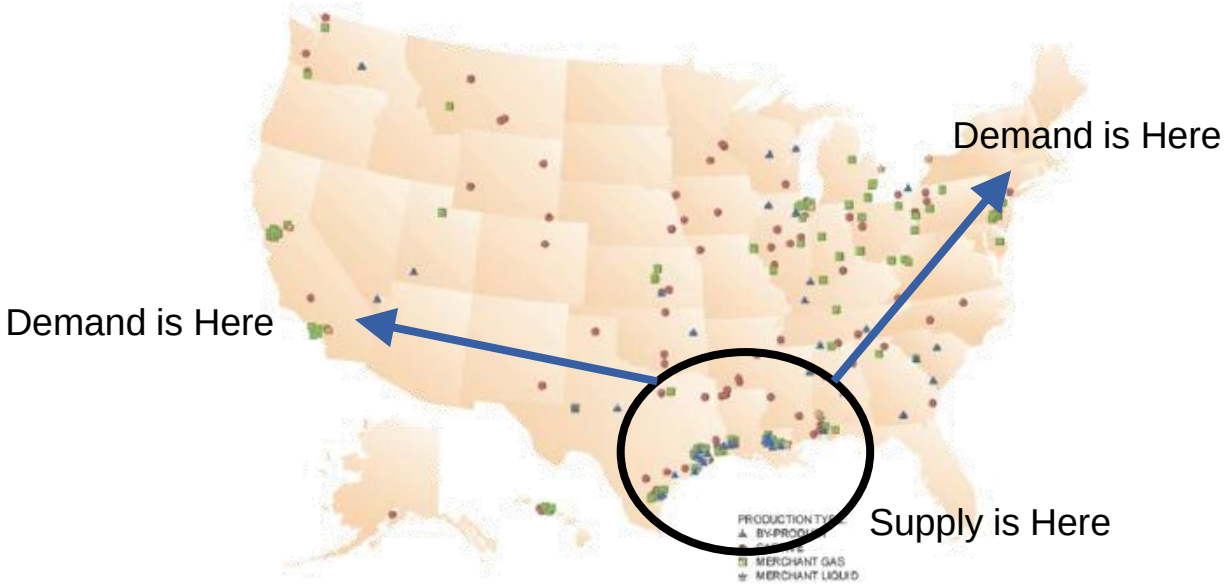
- **Scale: 100-200 MW - economically interesting for grid operators; need low cost power**
- **Scale: 10-60 TPD - matched to size of liquifier**
- **Cost Competitive: Needs to be a consideration for refinery hydrogen production**

Challenges @Scale

Economics - Hydrogen is not a commodity - more like "mobile data" than gasoline - purchased as a service, not a product.

Policy - Biogas is valuable for traditional energy as well as hydrogen energy. Renewable H2 production policies should identify and prevent potential incentive conflicts.

Location: Distribution costs are non-trivial.



Centralized H_2 Production Facilities

What can FCTO do?

- **Encourage Industry Relationships for High Risk Deployment opportunities**
  - Such as: 50 MW (20 TPD) Electrolyzer with 20 TPD Biogas SMR+Cogen and 30 TPD Liquifier

- **Identify and collaborate with other key user communities within Federal government - DOD, NASA**

- **Priorities:**
  - Distribution costs (e.g. trailers, filling centers, redundancy)
  - Electrolyzer @ Scale 100MW
  - Liquefaction technologies particularly at small scale;