AIR LIQUIDE

Hydrogen Delivery Technologies and Systems

Pipeline Transmission of Hydrogen

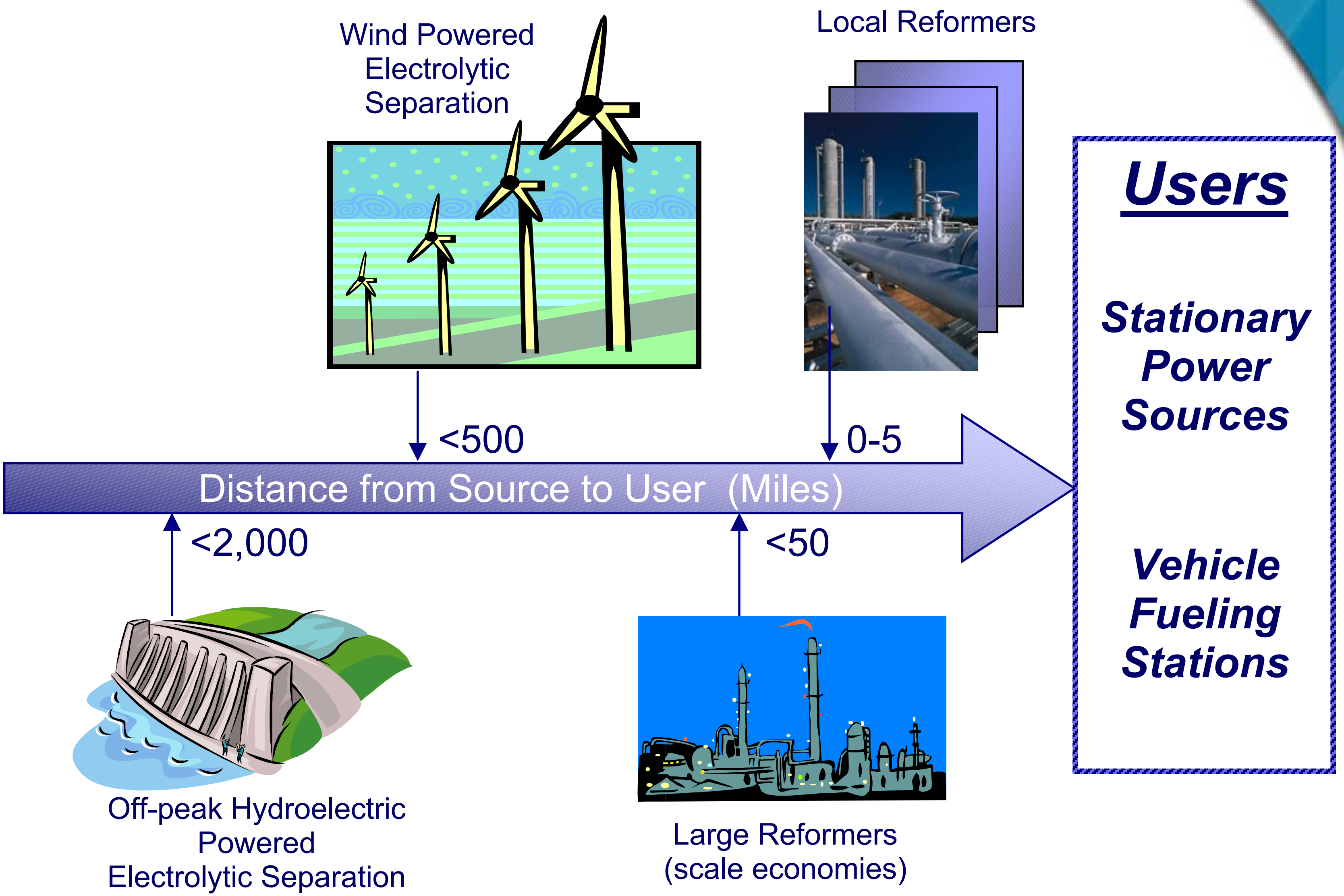
Strategic Initiatives for Hydrogen Delivery Workshop ■ May 7- 8, 2003
U.S. Department of Energy ■ Hydrogen, Fuel Cells, and Infrastructure Technologies Program

Design & Operation Standards

❑ *Relevant Design and Operating Standards*

- ANSI/ASME B31.8
- 49 CFR 192
- CGA H_2 Pipeline Standard (in development)

Future H_2 Infrastructure



Physical Properties

Data from Various Sources

		Natural Gas[1]		Hydrogen	
Heating Values		HHV	LHV	HHV	LHV
[2]	BTU/SCF	1,013	913	325	275
	BTU/lb	23,879	21,520	61,000	51,623
[3]	kJ/nm³	39,819	35,882	12,745	10,783
	kJ/kg	55,530	50,020	141,890	119,972
Min. Ignition Energy (mJ)		0.29		0.02	
Molecular Weight		16.04		2.02	
Viscosity @ SC	(lbm/ft-s)	7.43e-06		5.94e-06	
@ NC	(cP)	0.0104		0.0084	
Specific Gravity [4]		0.65		0.0695	

[1]- Data shown is for Methane *[2]– 70 DegF/14.7PSIA* *[3]– 0 DegC/1atm.* *[4]– air = 1.00*

Design & Operation

--- Special Issues for H_2 Service

❑ Leakage

- Gaskets and Seals are more critical (compared to Natural Gas)

- H_2 (commercial purity) has no odor.
  - ✓ Adding odorants as for Natural Gas, LPG etc. adds a contaminant that is poisonous to many fuel cell technologies
  - ✓ This will add cost to the H_2 energy picture, either in pre-treatment to remove the contaminants, or in reduced service life of the affected systems.

- Owing to the lower ignition energy and wider flammability limits, H_2 leaks are more likely to ignite than a Natural Gas leak.
  - ✓ But, lower flame temperatures produce fires that are less damaging than Natural Gas fires.

Design & Operation
--- Special Issues for H_2 Service

- ***Materials of Construction***
  - Hydrogen Embrittlement
    - ✓ Presence of atomic hydrogen in carbon steel (permeability)
    - ✓ Toughness or ductility of the metal is decreased
      - *Results in Cracking or Fissuring of the Metal*

      Potentially Catastrophic Failure of Pipelines!

Higher Strength Materials are more susceptible to Hydrogen Embrittlement.

H_2 Induced Cracking - photos

Examination in the scanning electron microscope reveals intergranular cleavage, characteristic of hydrogen embrittlement.

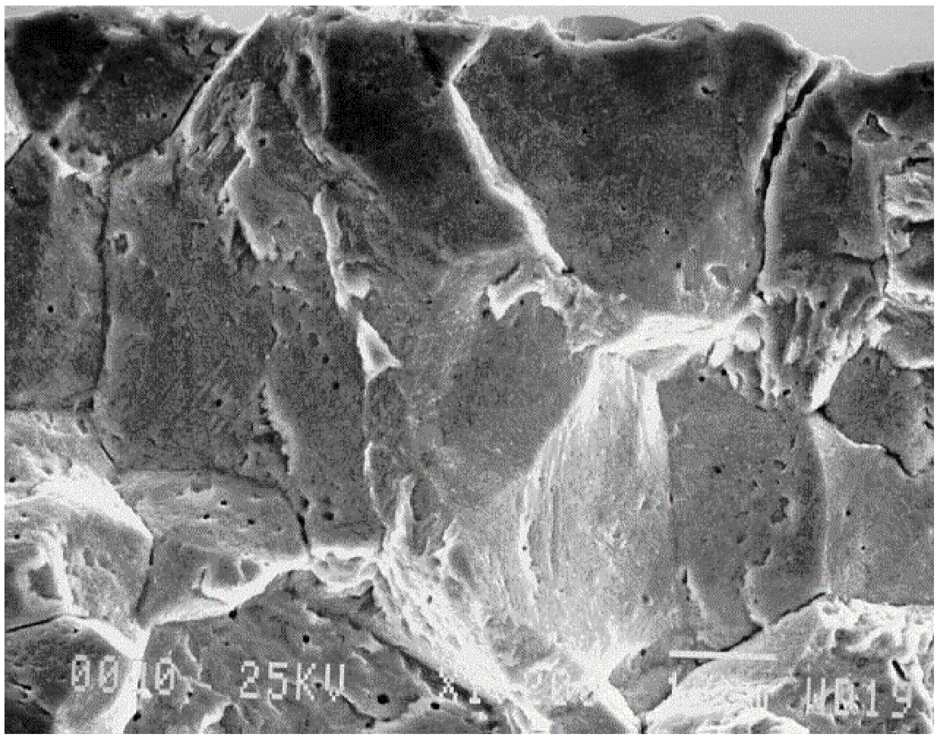


Photo Courtesy of NASA/Kennedy Space Center Materials Lab

Control of Hydrogen Embrittlement

- ***Avoid High Strength Steels***
- ***Avoid Pressure Cycles of the Pipeline***
- ***Limit Hardness of Pipe and Weld Materials***

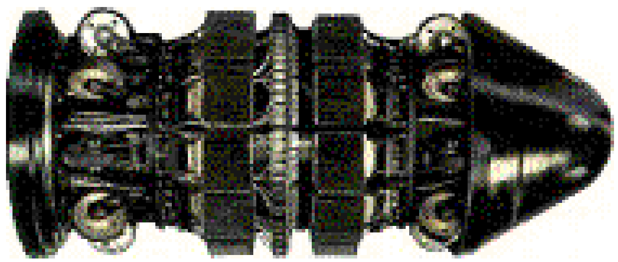
There is no consensus within the Technical community on specific limits discussed above. Additional research to establish design, construction and operating limits will be beneficial.

Design & Operation

❑ Conversion of Existing Pipelines to H_2 Service

- 200 miles recently converted from crude oil to H_2 service
- No problems specific to H_2 use
- Metallurgy may be a problem at elevated pressures
- Specific Inspection Techniques are necessary prior to conversion to H_2 service.

Pipeline Inspection Tools

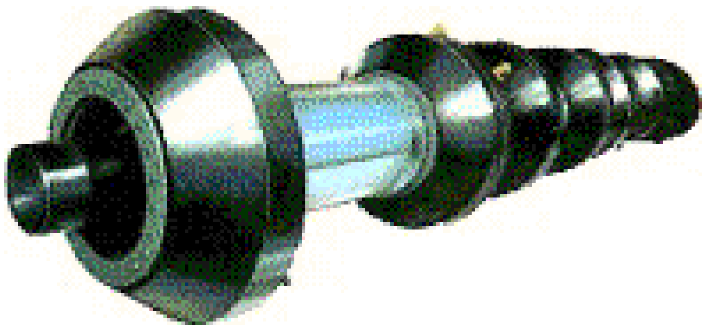


Smart Pigs can be introduced into operating pipelines and propelled by the gases or liquids being delivered. Smart Pigs for pipelines from 10” and larger have been developed.

Different technologies are used to locate defects in the pipeline wall.

Magnetic Flux Leakage (MFL) measurements can detect corrosion on thinning walls.

Ultrasonic sensors can detect external coating disbondment, cracks, dents and gouges.



The pigs contain data acquisition and storage devices. After the pig is recovered from the pipeline, the data can be downloaded. Analysis of the data reveals exact location of defects detected.

❑ Example - Compare H_2 and Natural Gas Compression & Pipeline Transmission:

- ***Compress from $P_{initial}$ = 1 to P_{final} =1000 PSIG***
- ***4-stage, inter-cooled compression equipment***
- ***Initial temp = 70 °F, Inter-stage temp = 90 °F***
- ***Compress the same volumetric quantity of each gas, i.e. XX million SCF/day:***

	Natural Gas	H_2
Delivered Energy consumed in the Compression Process	*0.31 %*	*1.33 %*

Transmission Energy Cost Considerations

- **But, Hydraulic characteristics of H_2 and Natural Gas are quite different:**
  - ***100 miles of 20" I.D. Pipeline***
  - ***Gas temp = 70 °F = constant***
  - ***Initial Pressure = 1000 PSIG***
  - ***Find volume rates of Natural Gas and H_2 delivered with 200 PSI ΔP:***

	Natural Gas	H_2
Volume of Gas Delivered (SCFH)	*7.0 MM*	*18.4 MM*

Transmission Energy Cost Considerations

❑ Combining Compression Energy and Hydraulic loss calculations:

	Natural Gas	H_2
Volume of Gas Delivered (SCFH)	*7.0 MM*	*18.4 MM*
LHV Energy Delivered (BTU/Hr)	*6,391 MM*	*5,060 MM*
Less Compression Energy (BTU/Hr)	*(20) MM*	*(69) MM*
Net Energy Delivered (BTU/Hr)	*6,371 MM*	*4,991 MM*

Transporting Hydrogen across the existing Natural Gas Infrastructure may result in a capacity "de-rating" (on a delivered energy basis) of approximately 20-25%.

Compressor and Valve Stations

- ❑ For conversions
  - ✓ Natural Gas compressors will need to be replaced
  - ✓ Valves, Fittings, & other Components may need replacement

Hydrogen's low Molecular Weight and Viscosity make sealing a problem. High performance valves, gaskets, etc. will be required to prevent leakage.

Conclusions

- Much of the Existing Natural Gas Pipeline Infrastructure could be converted to H_2 service.
  - ✓ Some limitations in Energy transmission capacity compared to Natural Gas.
- New H_2 pipeline construction cost should be comparable to Natural Gas pipeline construction costs.
- H_2 Compression Equipment Cost is much higher than Natural Gas Compression Equipment ($/BTU basis??)
- Safety Concerns for H_2 pipeline delivery should be no greater than for Natural Gas.