Compression Applications in the Use of Hydrogen for Carbon Reduction

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Powering the Future

1

Agenda

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- Introduction and Background
- Relevant Applications: Blue Hydrogen and Green Hydrogen
- What to do with Carbon Dioxide
- Hydrogen Challenges
- Power Generation: Blue vs Green vs Carbon Capture
- Storage
- Conclusions

2

Hydrogen Pathways

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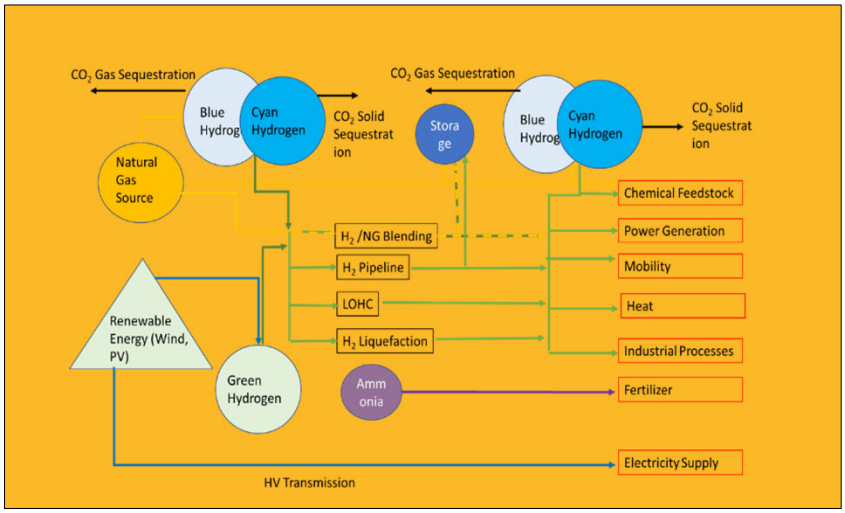
- How and Where is Hydrogen Generated
- Where is it used
- Transport



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Hydrogen: Methods for Storage of Renewables

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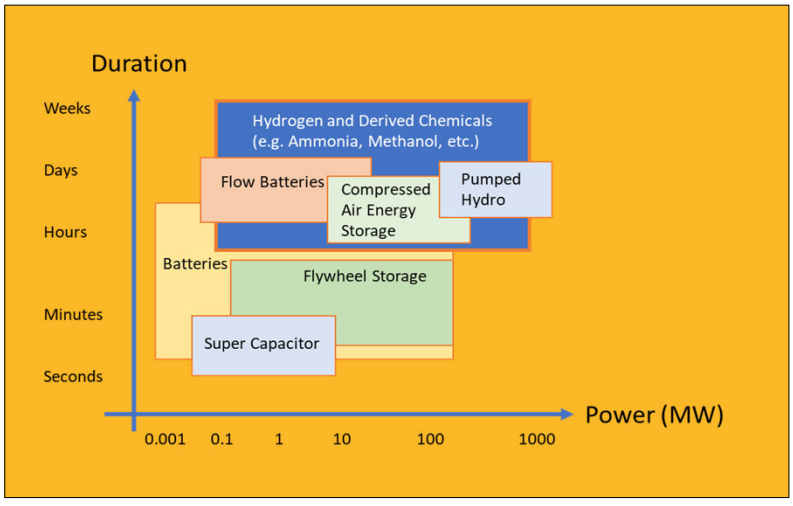

4

Blue and Green Hydrogen

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- Hydrogen has to be generated
- Green Hydrogen uses Renewable Electricity via Electrolysis
  - Transport and Storage
- Blue Hydrogen uses Fossil Fuel (Natural Gas) as Feedstock
  - Requires Energy
  - Natural Gas has to be Transported
  - Creates CO_2 that has to be Captured, Transported and Sequestered

We will have to talk about the transport
of
Hydrogen, CO_2 and Natural Gas

5

Thermodynamic Properties

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	Hydrogen	Natural gas	CO2
Heat capacity (kJ/kgK)	14.3	2.3	0.839
Ratio of heat capacities	1.4	1.3	1.3
Speed of sound (m/s)	1320	450	280

$$\frac{P_2}{P_1} = \left(1 + \frac{\eta}{c_p \cdot T_1} \cdot H\right)^{\frac{\gamma}{\gamma - 1}}$$

6

Hydrogen Applications

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- Compression Electrolyzer or SMR to Pipeline Pressure: 20 bar to 100 bar
- Pipeline Transport: Low Pressure ratio, 100 bar
- Storage: From pipeline pressure to 200-300bar
- Fuel Gas Compression to 20-30 bar (Gas Turbine), or 500-900 bar(automotive)

7

Hydrogen Compression

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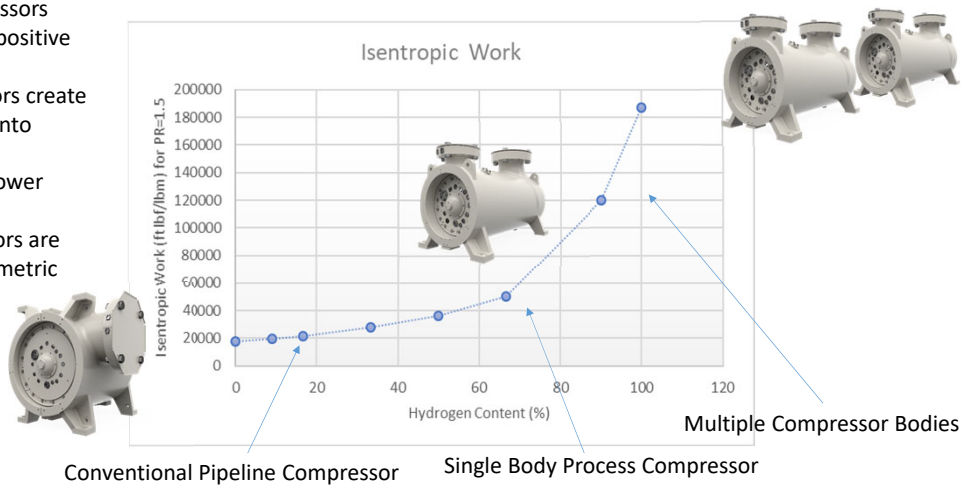
- Reciprocating Compressors create Volume Ratio (positive displacement)
- Centrifugal compressors create Head, that translates into pressure ratio
- This does not affect power consumption
- Centrifugal Compressors are capable of larger volumetric flows



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8

Hydrogen: Compression Power Requirements

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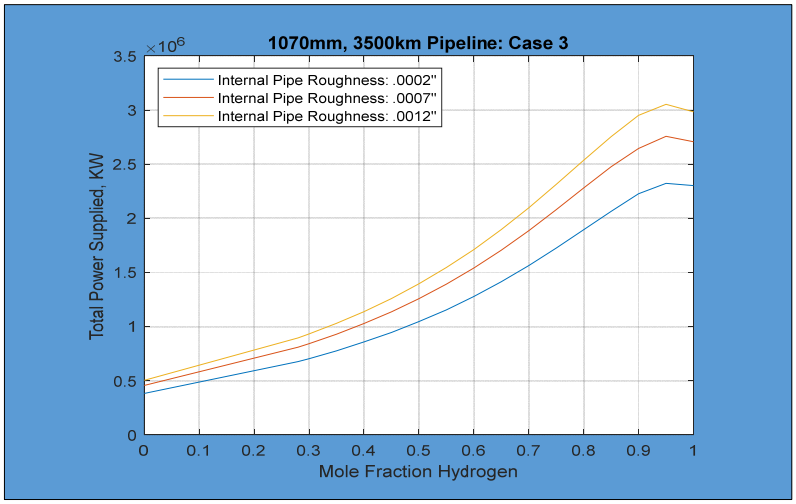

9

Impact of Fluctuating Hydrogen Content

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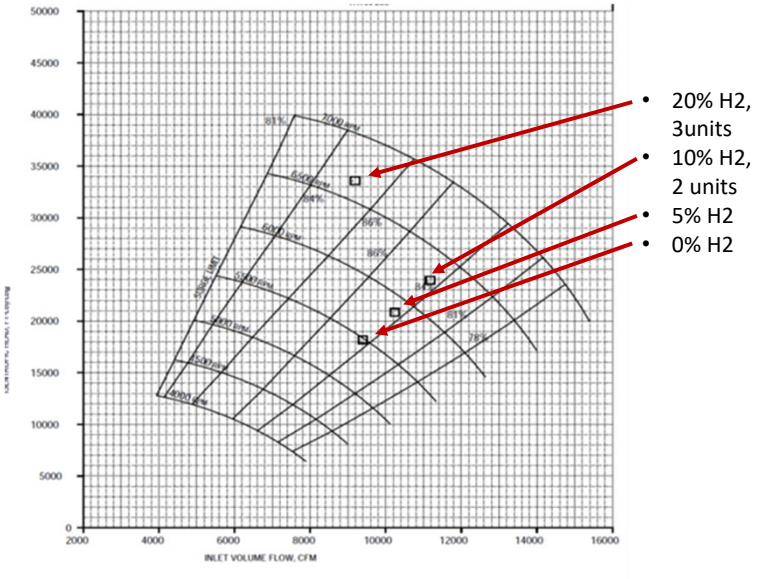
To maintain Energy Flow in the Pipeline:

- Best case: No pressure derate
- Higher power requirement
  - Likely additional units
- Higher Compressor Speed



10

Result of Adding Hydrogen

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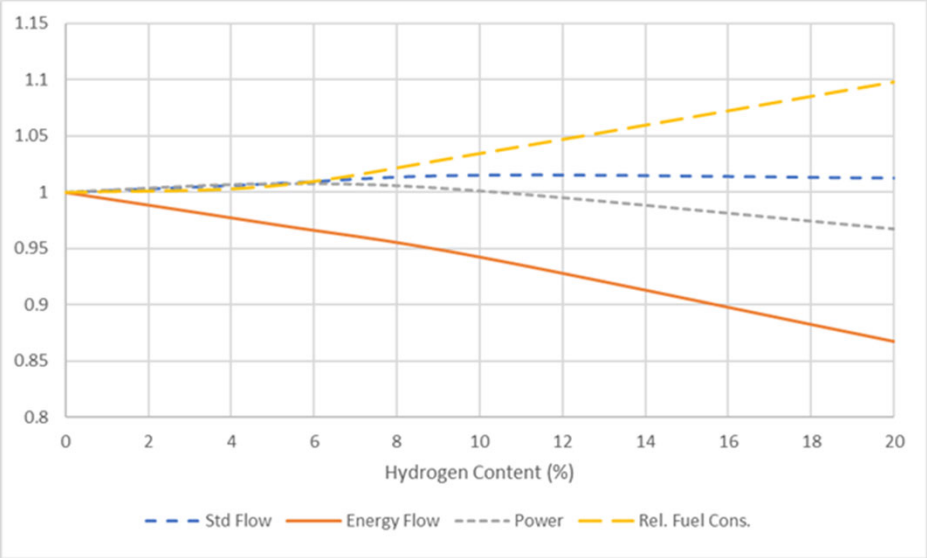

11

A Few Questions

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- Pure Hydrogen or Hydrogen mixed into Natural Gas?
  - What problem are we trying to solve?
- Centrifugal or Reciprocating?
  - Beyond a certain amount of Hydrogen, Reciprocating Compressors become impractical
- Electrons or Molecules?
  - If electricity is required as end result, creation of green hydrogen makes only sense as one of the competing storage options
  - If Hydrogen Molecules are required at the Receiving End (eg Steel Production, Fertilizer, Transportation…) , Hydrogen Transport may require less energy than Electricity Transport

12

What to do with CO_2

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Carbon Dioxide Applications

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- Carbon Capture: Atmospheric to 140 bar
- Carbon Transport: 90 to 140+ bar (dense phase)
- Carbon Sequestration (20/90 bar to 100/400+ bar)

14

Carbon Dioxide: Carbon Capture

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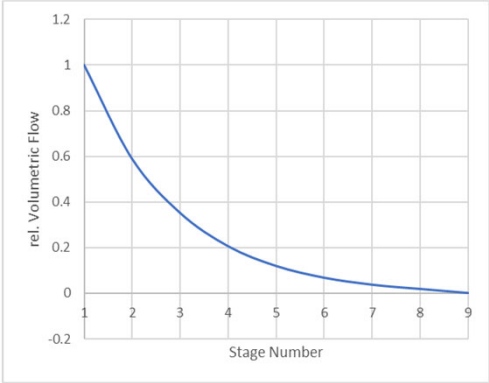

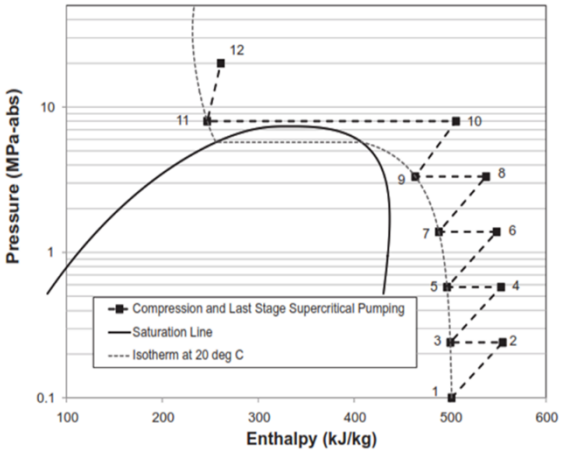

Volumes: A 1 GW power plant leads to about 120,000 acfm of CO2 at near atmospheric pressure

15

Carbon Capture: Compression Options

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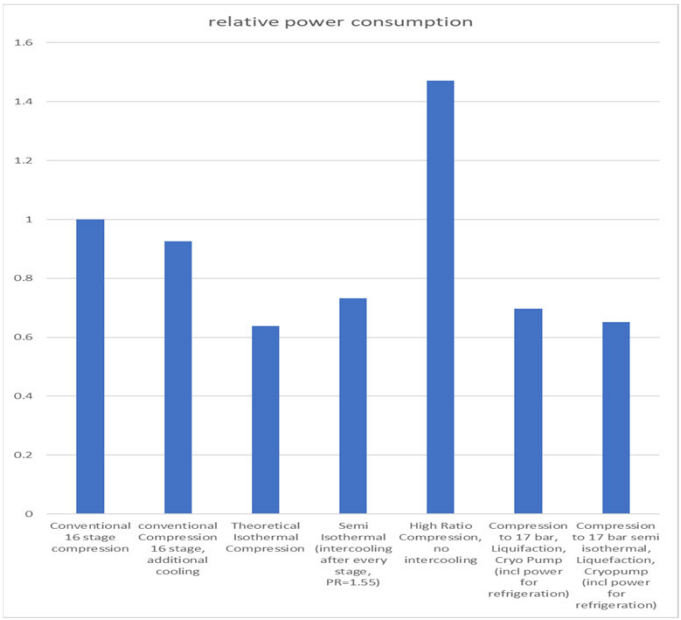

16

CO2 Transport

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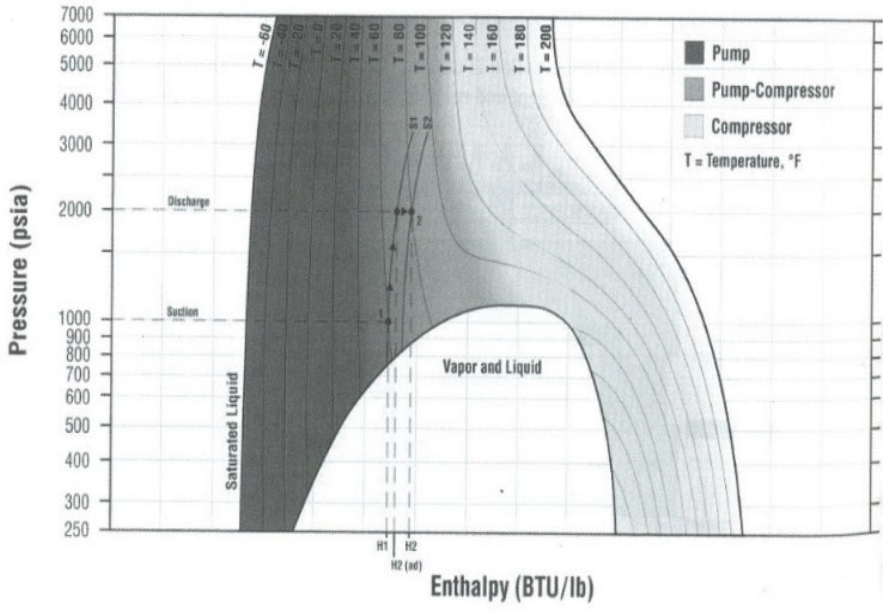
Dense Phase or Not?

-Dense Phase allows for very low Power demand. Pressure exceeds capability of existing NG pipes

-Low pressure would allow re-use of NG pipes, but at a much lower pressure, and much higher power consumption



17

CO2 Sequestration

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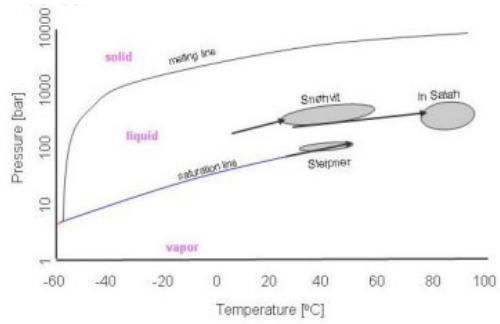

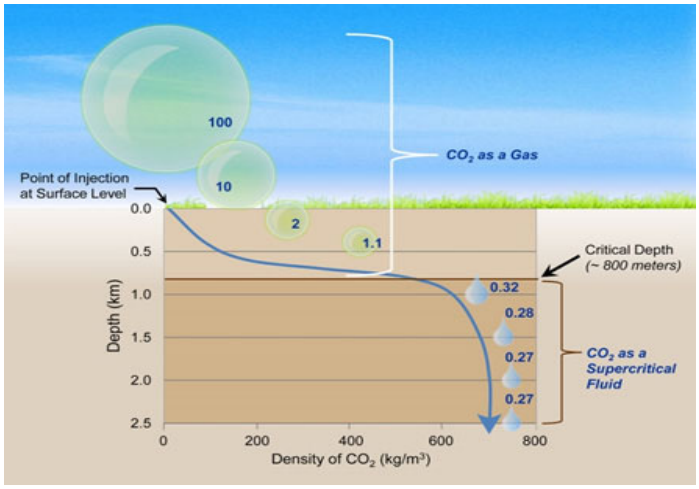

18

Power Plant Options for Carbon Avoidance

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- Transport Hydrogen to a Power Plant
- Transport Natural Gas to the Power Plant, and
  - Make Blue Hydrogen, using SMR, or
  - Use Natural Gas as a Fuel, and Capture the CO2 in the exhaust

19

Transport: Pipeline Simulations

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- A dense phase CO_2 pipeline with 32'' nominal diameter, 3 compressor stations equally spaced, transporting about 766 kg/s or 1300 MMSCFD, for a distance of 500 miles (800 km). The operating pressure is 2200 psig, and the inlet pressure for the compressor station is kept at above 1320 psig to avoid two-phase flow at all prevailing ambient temperatures. The calculations shown are for 37.8 °C (100 °F) gas temperature at the head station discharge.

- A hydrogen pipeline for the same distance (500 miles,800km), 1440 psig operating pressure, transporting 1000 MMSCFD, also with 3 compressor stations equally spaced.

- A 500miles (800km) natural gas pipeline, for 700 MMSCFD, 1440 psig operating pressure, gas with SG=0.58.

20

Transport: Pipeline Simulations

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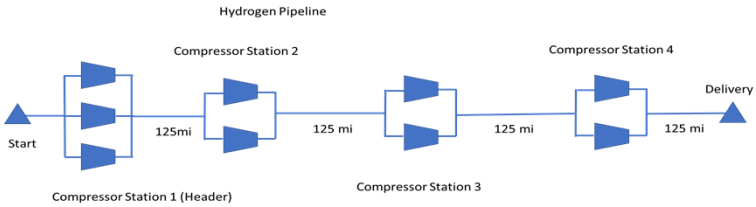
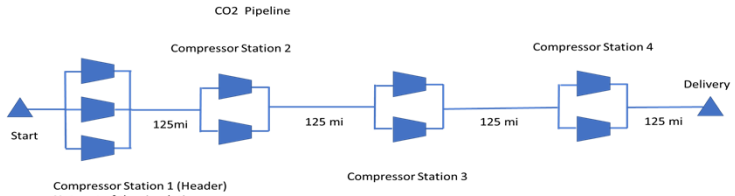


Avg flow velocity: 40 ft/s
Operating Pressure: 1440 psig
Start pressure 200psig
Delivery Pressure: 1200psig

Hydrogen Pipeline

CO2 Pipeline



Avg flow velocity: 6.5 ft/s
Operating Pressure: 2200 psig
Start pressure 2220psig
Delivery Pressure: 1328 psig

22

Relative Power Requirement for Transport

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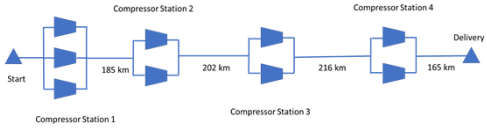

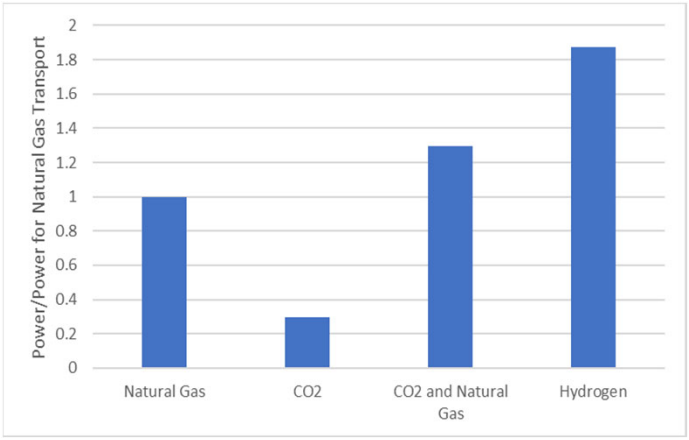

Gas Flows related to a 1GW Power plant

25

Blue Hydrogen or Carbon Capture with EGR

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The techno-economic analysis suggests that doing CC with EGR (post-combustion) may be a better approach than using SMR to make H2. EGR will be more efficient, will produce a lesser amount of CO2 at a given power level, and will not need nearly as much water as the SMR. A bottoming cycle will be complimentary to EGR since the exhaust temperature needs to be reduced anyway. (Burnes et al., ASME GT2022-83472)

TABLE 3: Performance Comparison to Pre- and Post-Combustion CC Configurations and a Bottoming Cycle Configuration relativized versus the Baseline

Configurations	Baseline	Pre-Comb - SMR	Post-Comb - EGR	Baseline+Bottoming Cycle
Gas Turbine Available Power (Full Load)	1.000	1.053	1.010	1.333
Demand Power	1.000	1.000	1.000	1.000
Thermal Efficiency of Gas Turbine	1.000	1.026	0.992	1.333
Parasitic Power rel to Full Load - %	0.0%	10.0%	10.0%	1.0%
Net Power Delivered After Parasitics	1.000	0.947	0.909	1.319
System Efficiency	1.000	0.749	0.892	1.319
Carbon Intensity prior to Capture	1.000	1.454	1.121	0.758

Water

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Blue Hydrogen requires 4.5 kg of Water per 1 kg of Hydrogen
Green Hydrogen requires 9 kg of Water per 1 kg of Hydrogen

Note: This is the water requirement for the reaction. Overall water usage is much higher

Impact on Power Plant discussions

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- Blue Hydrogen: Hydrogen generation likely near power plant
- Green Hydrogen: Transport Path Costly, unless the end use is for Hydrogen, not for electricity
- Blue Hydrogen with Carbon Capture vs. Burning Natural Gas with Carbon Capture

28

Storage (H_2 and CO_2)

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- Geological Formations
  - Hydrogen
  - CO_2
- CO_2 Permanent, H_2 Storage/Withdrawal
- Depleted Oil and Gas Fields, Natural Aquifers, Salt Caverns
- Concerns: Gas Tight? Solubility? Stratification?
- Pressures:
  - CO2: 200 bar (3000psi) or less in abandoned gas fields, below about 250 bar (3750 psi) in aquifers. Injection for enhanced oil recovery (EOR) could be 200 to 400 bar or higher.
  - Hydrogen: Salt Caverns, 200 – 250 bar?
- Flow capability (injection/withdrawal rates) is to some extent determined by facility limitations (for example, erosion limits).

29

Conclusions

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- Reduction of Carbon Footprint requires a number of specific compression and transport duties.
  - Hydrogen
  - Natural Gas
  - CO_2
- Transport and Compression of Hydrogen is very Energy Intensive
- Compression of CO2 in the Capturing Process is very Energy Intensive
- Hydrogen transport is more power intensive than CO2 and Natural Gas Transport Combined.
- Decisions to be made in discussions of blue vs green hydrogen vs. Carbon Capture

30

THANK YOU

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31