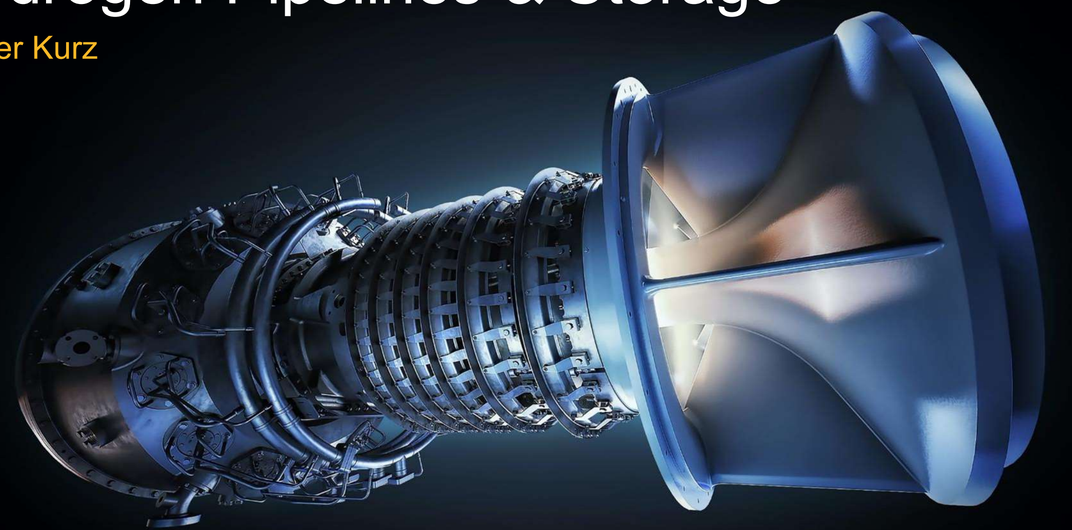
Hydrogen Pipelines & Storage

Rainer Kurz



Solar Turbines
A Caterpillar Company

Powering the Future

1

Overview

Solar Turbines
A Caterpillar Company

- Hydrogen Properties
- Applications
- Hydrogen Compression
- Drivers
- Pipeline Transport
  - Pipelines and Hydrogen
  - Existing Pipelines
  - Carbon Balance Sheet
- Storage

2

Hydrogen Properties

Relevant Hydrogen Properties

Solar Turbines
A Caterpillar Company

It's lighter

It carries less energy per unit volume

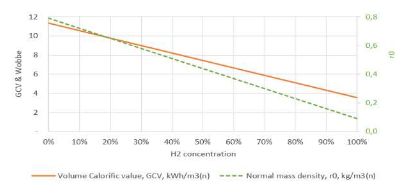
It carries more energy per unit mass

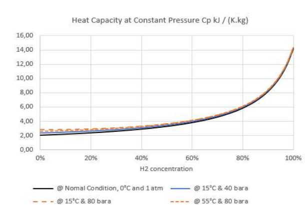
Higher Heat capacity

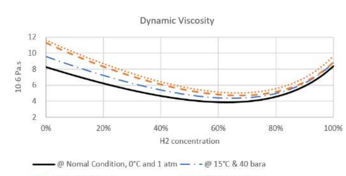
Different Viscosity

Very high speed of Sound

  H2: 1270 m/s, Methane 446 m/s, CO2 267 m/s







Applications

5

The Colors of Hydrogen

Solar Turbines
A Caterpillar Company

- Gasification of solid fuels like coal, pet coke, biomass, municipal waste into a syngas. This contains CO, CO_2 and other things, and is then processed to recover H_2. This is referred to as brown hydrogen
- Steam Methane Reforming (SMR): Using steam to split methane into H_2 and CO_2. This is referred to as grey hydrogen.
- Steam Methane Reforming (SMR): Using steam to split methane into H_2 and CO_2. The CO_2 is generally sequestered as part of this process. This is referred to as blue hydrogen.
- Pyrolysis: Thermal decomposition of methane into H_2 and solid carbon dust. The carbon dust can be sequestered. This is referred to as cyan (or turquoise) hydrogen.
- Electrolysis: Using electricity (often using excess renewables) to split H_20 into hydrogen and oxygen. This is referred to as green hydrogen

6

Transport Applications

Solar Turbines
A Caterpillar Company

- Green or Blue Hydrogen mixed into Natural Gas Pipelines
- Green or Blue Hydrogen transported in pure form in Pipelines
- Transport of CO_2 from Blue Hydrogen (or Exhaust) to Sequestration Site
- Transport of Natural Gas to Power Plant or SMR site
- Storage (to Balance Supply and Demand)

7

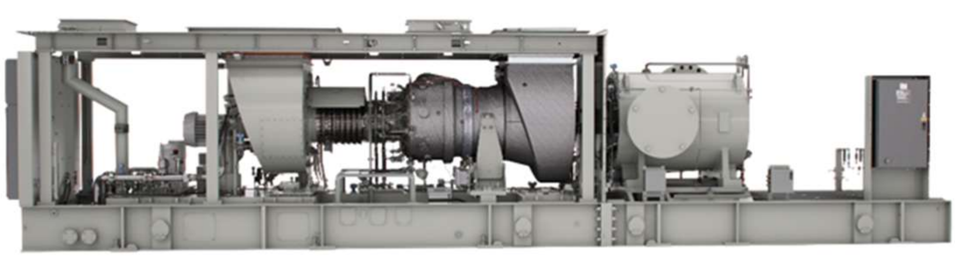
Impact Areas Using H_2 and H_2 Rich NG

Solar Turbines
A Caterpillar Company

Gas Turbine
- Injector Flashback
- Pollutant Emissions
- Combustion Stability
- Controls & Operability
- Thermal Durability

Package
- Package Safety
- Start-up & Controls
- Flameout Detection
- Enclosure Flame Detection
- Fuel System Materials

Compressor
- Performance
- Materials – Metals & Seals
- Operating Conditions



8

Compression

9

Pressure Ratio and Head

Solar Turbines
A Caterpillar Company

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

	Hydrogen	Natural Gas	CO2
Heat Capacity (cp, kJ/kgK)	14.3	2.3	0.839
Ratio of Heat Capacities (γ)	1.4	1.3	1.3

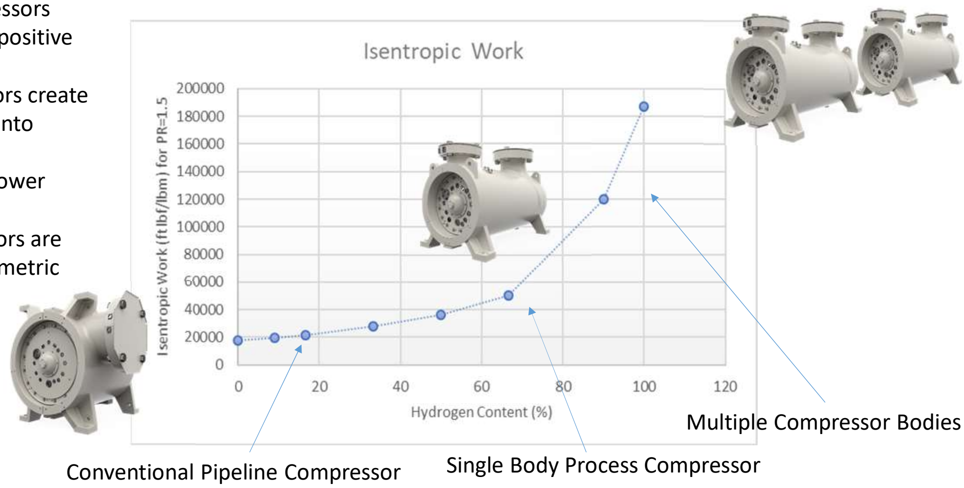
10

10

Hydrogen Compression

Solar Turbines
A Caterpillar Company

- 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



11

11

Design Challenges of Pure Hydrogen Compression

Solar Turbines
A Caterpillar Company

- Light gas compression
  - Low pressure ratio
  - Many stages (mechanical/rotordynamic) or high speed (high stress, novel materials)
  - Equation of state
- Sealing
  - Dynamic (seal leakage, scavenging)
  - Static (soft component hydrogen permeability and decompression bubbling)
- Materials and coatings
  - Hydrogen embrittlement (material loses ductility due to H2 penetration)
  - Coating loss and disbonding
- Safety:
  - Explosivity, wide flammability range, dispersion and impact radius, leak detection

12

12

Drivers

13

Drivers

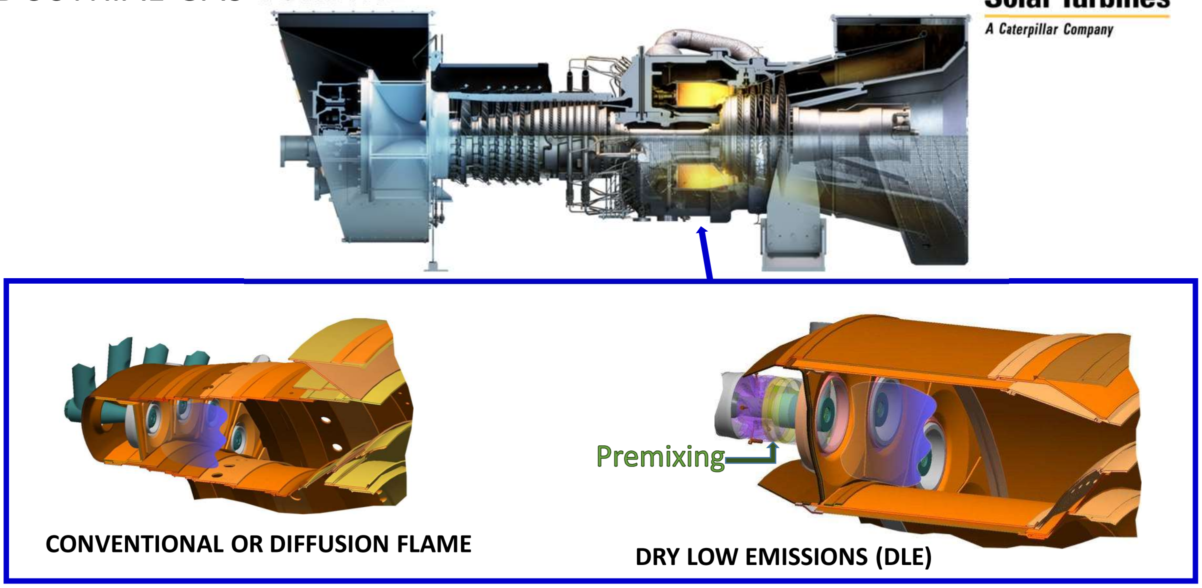
Solar Turbines
A Caterpillar Company

- For Centrifugal Compressors
  - Gas Turbines
  - Electric Motors
- For Reciprocating Compressors
  - Gas Engines
  - Electric Motors

14

INDUSTRIAL GAS TURBINE

Solar Turbines
A Caterpillar Company

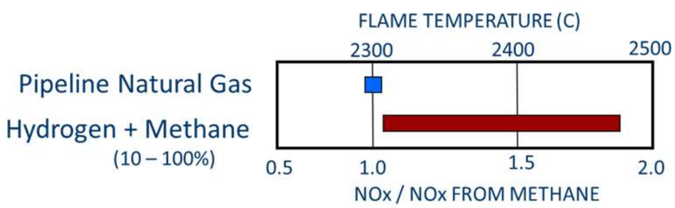


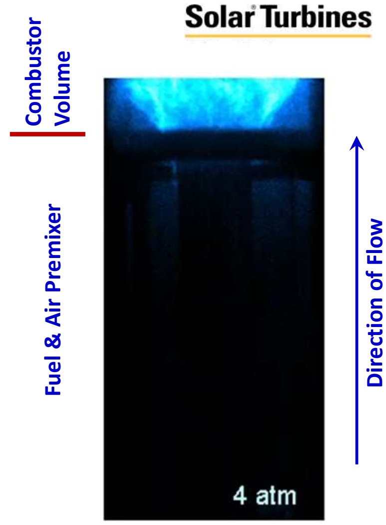
15

Hydrogen Combustion Characteristics

Solar Turbines

- Higher Flame Speed – H_2 is 7x Faster
  - Flame Position in Combustor - “Flashback” Risk
  - 20% H_2 and Below only 15% Faster
- Higher Flame Temperature
  - Higher NOx Emissions





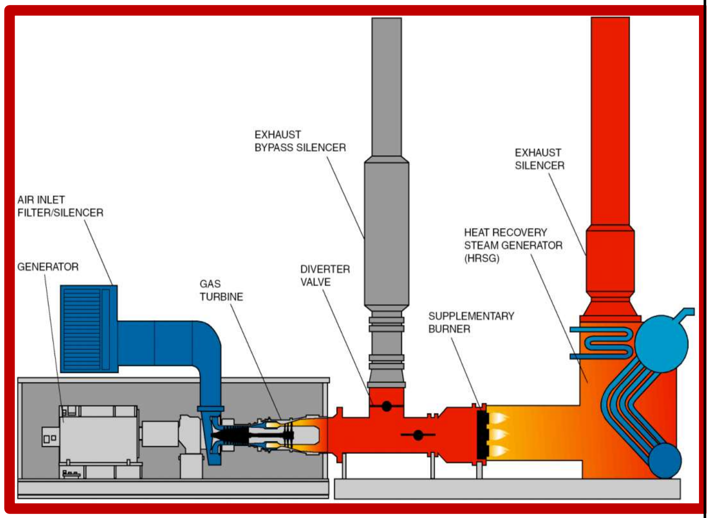
Flashback in DLE Injector

16

Compressor Set Package – H2 Safety

Solar Turbines
A Caterpillar Company

- Fire and Gas Detection
- Fuel System - Engine & Package
- Electrical Devices
- Control System Software
- Package Ventilation
- Engine & Ancillary Exhaust System



17

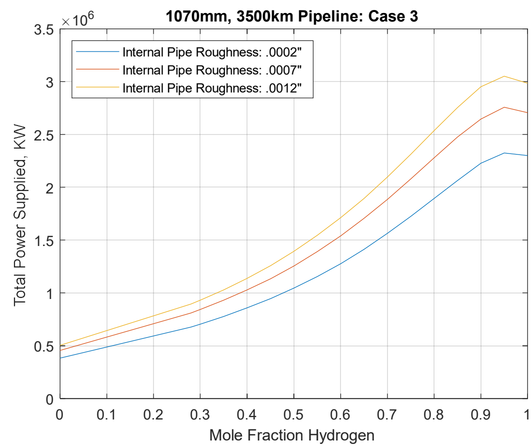
Pipelines and Hydrogen

18

H_2 Blending Increases Compression Work

Solar Turbines
A Caterpillar Company

- Compression work is increased by
  - Higher pressure drop between stations
  - Lower molecular weight of H2
- At 100% H2, increase in compression head rises by ~1x order of magnitude
- Power increases by ~5x



ASME GT2021-59398

19

19

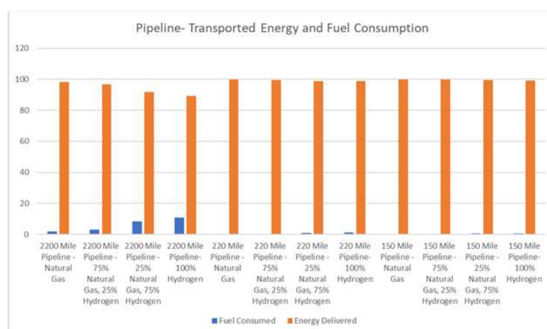
Pipeline Transport –Energy Consumption

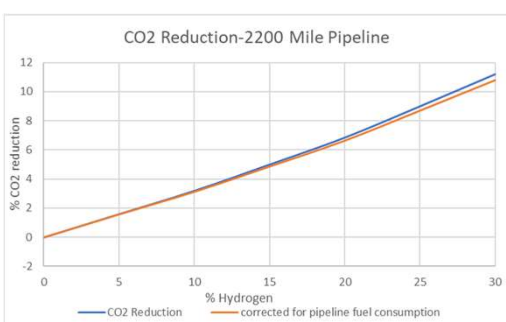
Solar Turbines
A Caterpillar Company

Transporting Gas in a Pipeline is very efficient

Only a small fraction of the transported gas is consumed as fuel

CO2 reduction effect only slightly affected



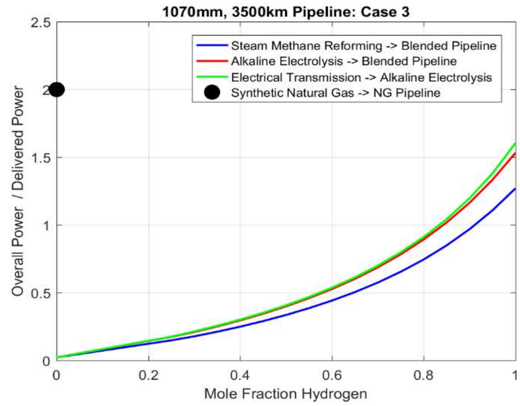


20

Why Hydrogen In Pipelines

Solar Turbines
A Caterpillar Company

- Transport of Green or Blue Hydrogen
- Storage Capability (in the Pipeline and in Storage Fields) to balance renewable energy production and energy demand
- If Hydrogen Gas is needed at the endpoint, more attractive energy transport than electric power lines



OVERALL POWER REQUIREMENT INCLUDING HYDROGEN/METHANE PRODUCTION AND TRANSPORT FOR VARIOUS POWER TRANSMISSION ARCHITECTURES, CASE 3

Allison, Klaerner, Cich, Kurz and McBain, Power and Compression Analysis of Power-to-Gas Implementations in Natural Gas Pipelines with up to 100% Hydrogen Concentration, ASME Paper GT2021-59398

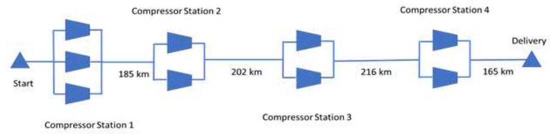
21

Natural Gas-Hydrogen Pipeline Transport

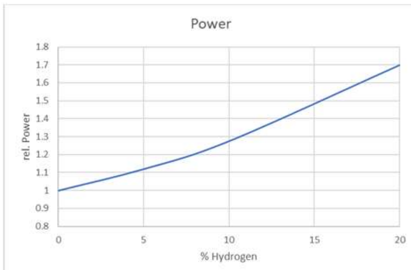
22

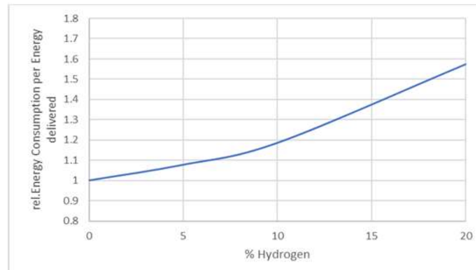
Solar Turbines
A Caterpillar Company

Pipeline Simulation



Assumption for study: Constant energy flow at delivery point





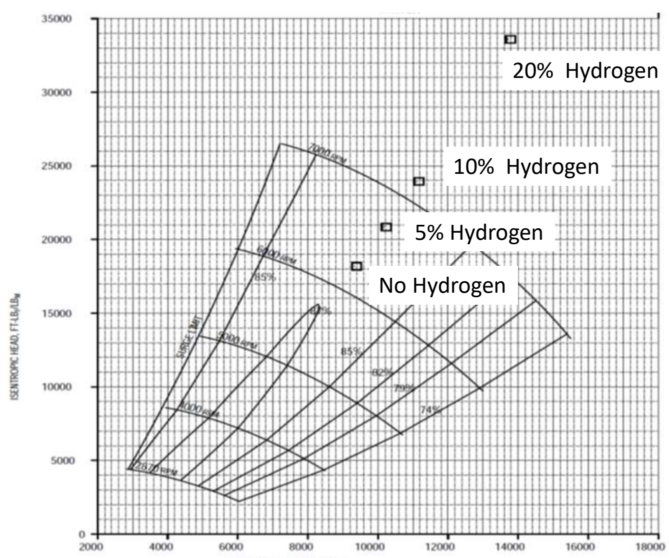
Power Consumption and Transportation efficiency of the pipeline as a function of hydrogen content in the pipeline gas. The amount of energy transported in the pipeline is kept constant. Both curves depend on pipeline geometry

23

Impact of Hydrogen: Compressor

Solar Turbines
A Caterpillar Company

- Change in operating points for one of the pipeline compressors with changing hydrogen content in the pipeline gas.
- Compressor sized for the pipeline with 0% hydrogen content.
- Power Consumption is increased
- The amount of energy transported in the pipeline is kept constant

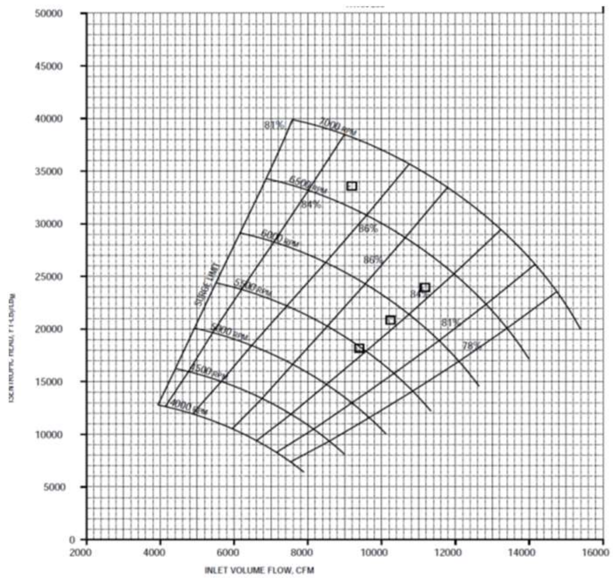


24

Increased Power Demand Adding a Compressor

Solar Turbines
A Caterpillar Company

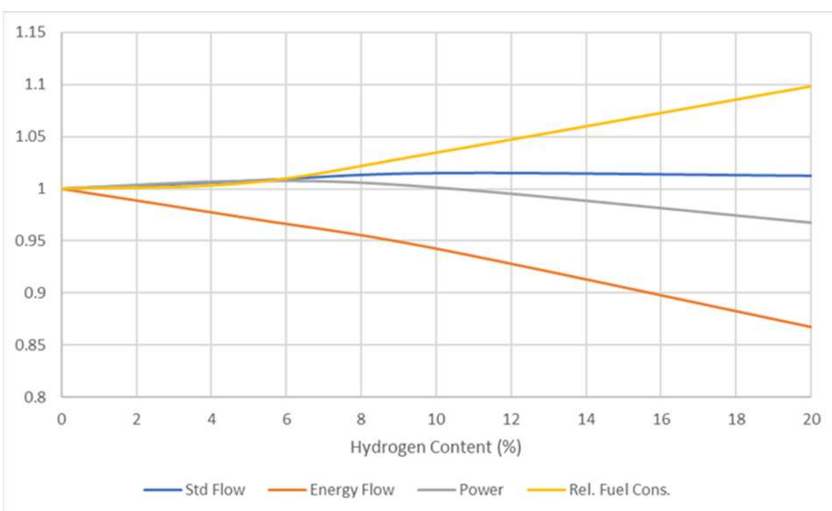
- Change in operating points for one of the pipeline compressors with changing hydrogen content in the pipeline gas.
- 3 units running for 20% Hydrogen content
- 2 units are running when the Hydrogen content is 10% or less.
- The amount of energy transported in the pipeline is kept constant.



25

Flow, Power and Fuel Consumption (No Changes to Pipeline)

Solar Turbines
A Caterpillar Company



26

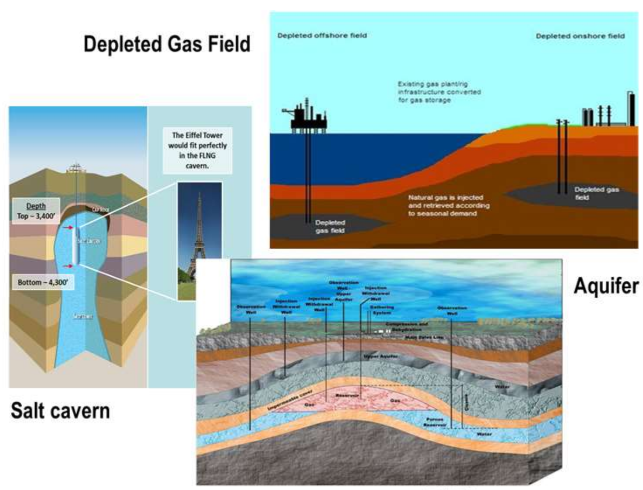
Storage

27

Storage Issues

Solar Turbines
A Caterpillar Company

- Suitability?
  - Salt Domes
  - Gas/Oil Fields
  - Aquifer
  - Artificial
- Stratification
- High Pressure Tanks
- Liquids
  - LH2
  - LOHC (Liquid Organic Hydrogen Carriers)
  - Ammonia



28

Conclusion

29

Summary

Solar Turbines
A Caterpillar Company

- Hydrogen Transport in Pipelines provides advantages over other transportation methods.
- Hydrogen can be used as a means of Energy storage.
- CO_2 reduction
- Same total energy delivered requires increase in compressor power due to higher pipe velocities and pipe pressure losses, as well as higher thermodynamic compressor work.
- Even modest increases in H_2 result in significant increases in required power or a reduction in pipeline capacity
  - Solved by restaging and additional power at the stations

30

31

31

32