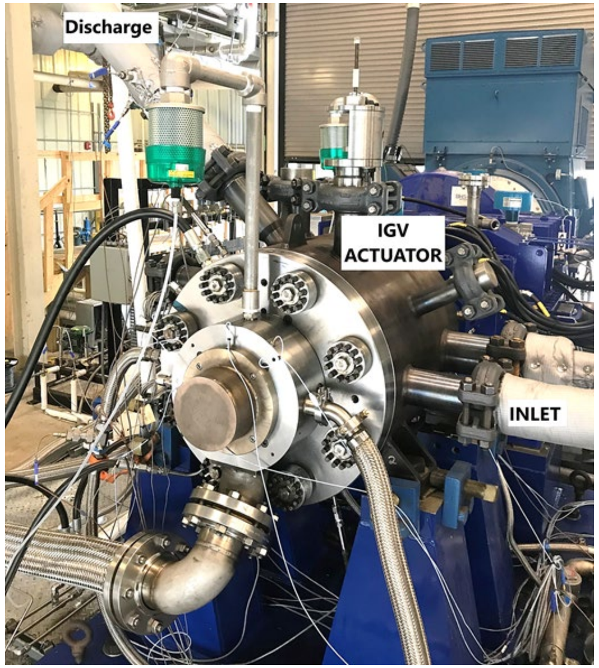
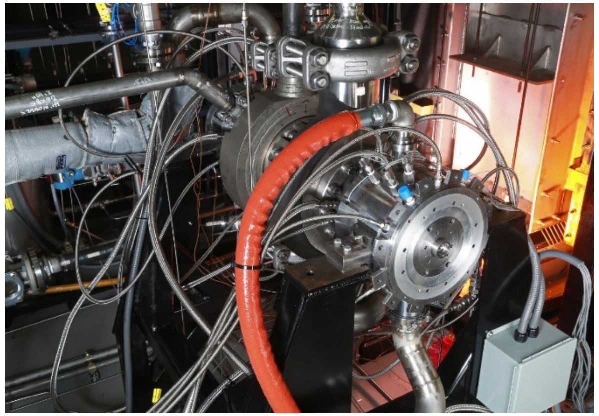
Development of sCO_2 Turbomachinery and its Application to Energy Storage



Jeff Moore, Ph.D.

Southwest Research Institute



7th International sCO2 Power Cycles Symposium

February 21-24, 2022

San Antonio, TX

Introduction

- Energy storage technologies are rapidly developing in response to increasingly large fluctuations in power demand and availability from intermittent resources including renewables
- New cycles require custom turbomachinery designs
- SCO_2 power cycles are being developed for both indirect and direct fired configurations
- SCO_2 cycles being considered for energy storage
- This presentation focuses on development of SCO2 turbomachinery to meet these challenging requirements

Thermochemical ES: CO_2 Phase Change

- **Combined with Thermal ES, which uses excess solar energy and stores in molten salt.**
- **Excess energy from the grid is used to cool liquid CO_2 to solid (dry ice)**
- **Release heat from salt to expand CO_2 from solid to supercritical fluid**
- Turbomachinery Integration
  - Turbine development for high-temperature, high-pressure CO_2
- Current TRL: 2-3
  - Component tests
- Technology Gaps
- Expected Performance
  - 68% efficiency
- R&D Activities
  - GE GRC through the ARPA-E FOCUS program
  - Echogen Power Systems with ARPA-E DAYS

E Q

Charge
Energy to cool liquid CO_2 to solid
Heat into molten salt

Store
CO_2 as solid (dry ice)
Heat in molten salt

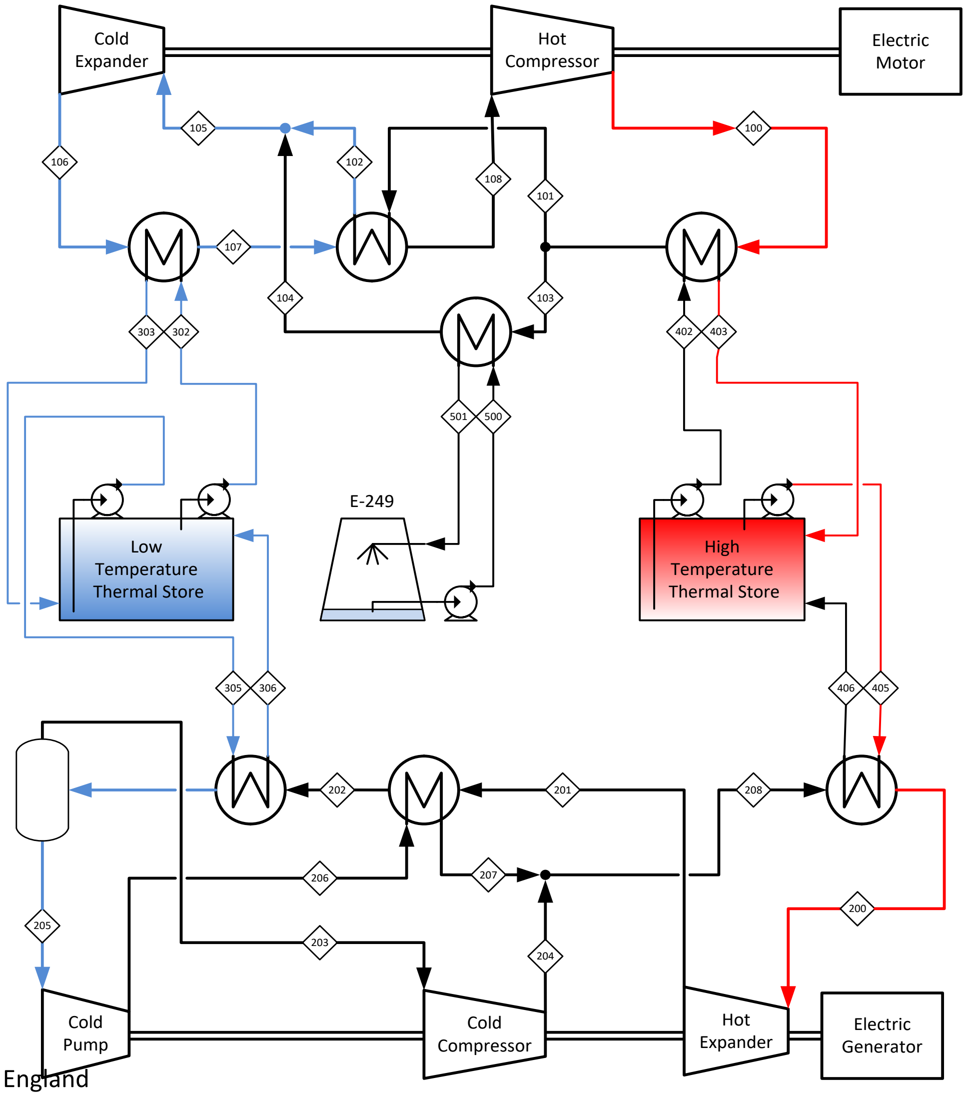
Discharge
Use heat from salt to change solid CO_2 into sCO_2
Expand sCO_2 across turbine

GE GRC

Trans-critical CO2 cycle

- Permits water ice cold storage, modest hot storage temperature (580°C)
- Competitive with ideal gas cycles at higher pressures

Parameter	Unit	Ideal gas cycle	Transcritical CO_2 Alt 1	Transcritical CO_2 Alt 2
Round Trip Efficiency	%	57.86	51.54	61.24
Heat Pump COP	–	1.31	1.78	1.34
Engine Efficiency	–	0.44	0.29	0.46
Charging Pr	–	3.82	7.63	14.23
Discharging Pr	–	5.17	6.78	15.11
Cycle Max Temperature	°F	1050.0	610.0	1049.0
Cycle Min Temperature	°F	−73.6	23.0	23.0
Cycle Max Pressure	psia	500.0	3905.0	8702.3

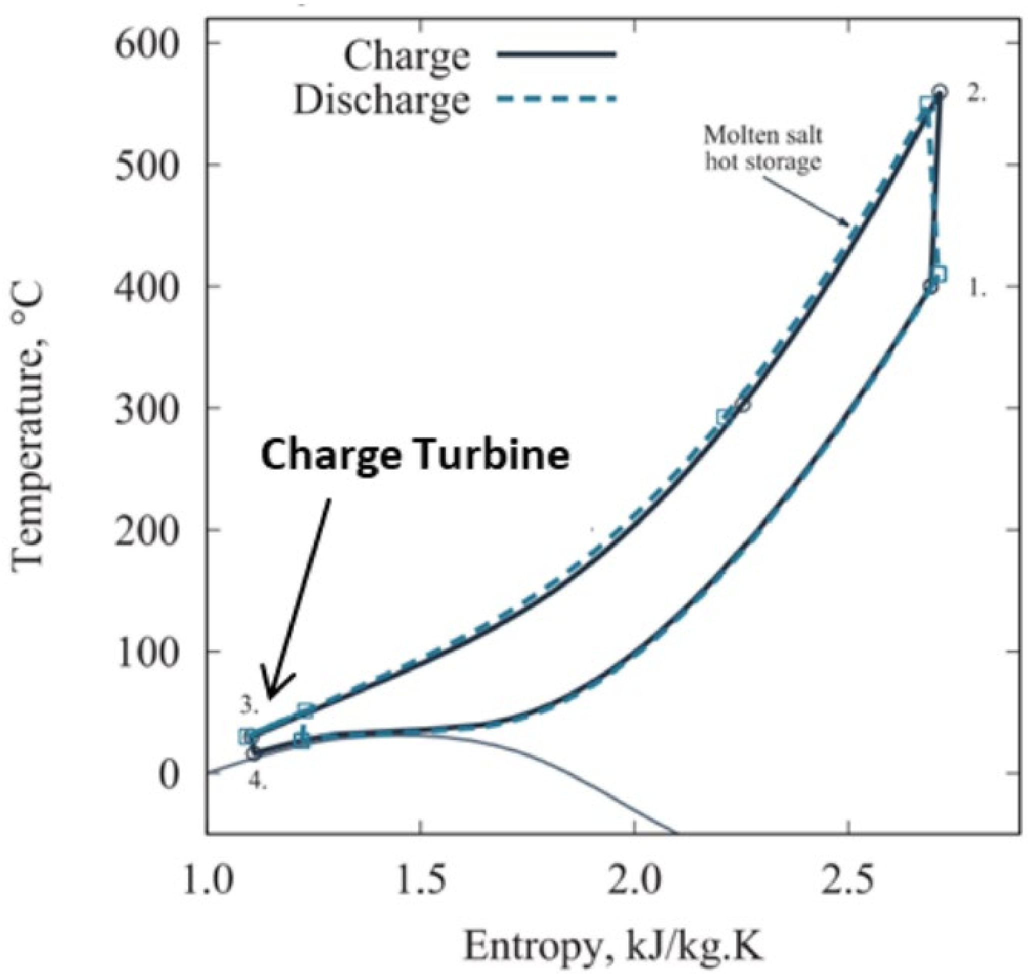


Process schematic, Transcritical-CO2 cycle

Ref: Brun, K., Allison, T., Dennis, R., 2021, ***Thermal, Mechanical, and Hybrid Chemical Energy Storage Systems***, Elsevier Academic Press, London, England
Contribution by Jason Kerth, Siemens Energy

Echogen Hybrid PTES

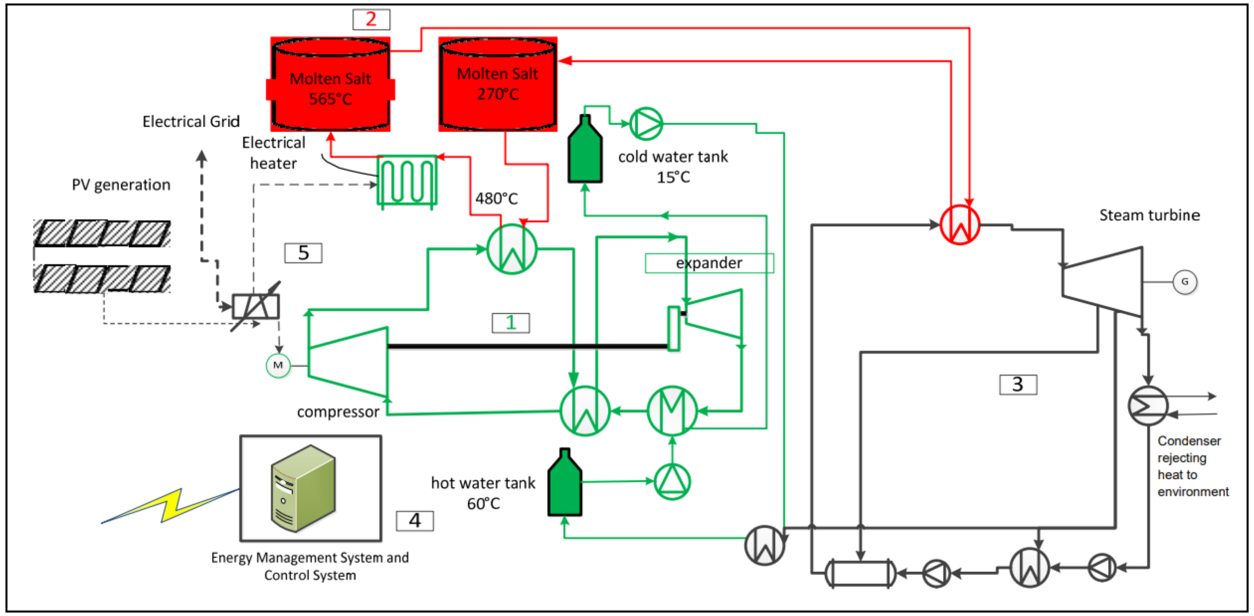
- PTES runs as a heat pump using heat of compression
  - Molten salt thermal storage
- Condensing SCO2 Charge Cycle for cold storage
  - Research proposed to understand effects of multi-phase flow on turbine reliability
  - Will utilize SCO2 pump loop at SwRI to test condensing turbine
- SwRI and Flowserve supporting development



[1] McTigue, Farres-Antunez, Ellingwood, Neises, White, 2020, "Pumped thermal electricity storage with supercritical CO2 cycles and solar heat input," AIP Conference Proceedings 2303, 190024.

GE SCO2/Steam Pumped Heat Cycle

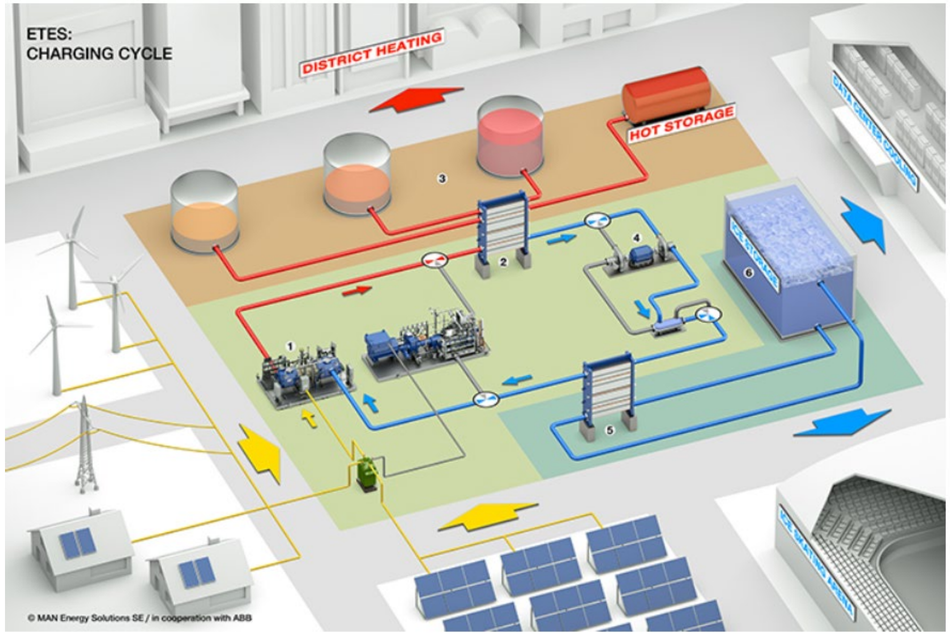
- SCO2 heat pump with molten salt thermal storage for charge cycle up to 480°C (current SCO2 compressor limit)
- Electric resistive heating used to heat to 565°C
- Discharge cycle using standard water steam cycle.
- Cold storage as water
- Leverages existing equipment as much as possible



Aga, V., Conte, E., Carroni, R., Burcker, B., Ramond, M., 2016, “Supercritical CO2-Based Heat Pump Cycle for Electrical Energy Storage for Utility Scale Dispatchable Renewable Energy Power Plants,” 5th International Symposium - Supercritical CO2 Power Cycles March 28-31, 2016, San Antonio, Texas

MAN/ABB Electro-Thermal Energy Storage (ETES)

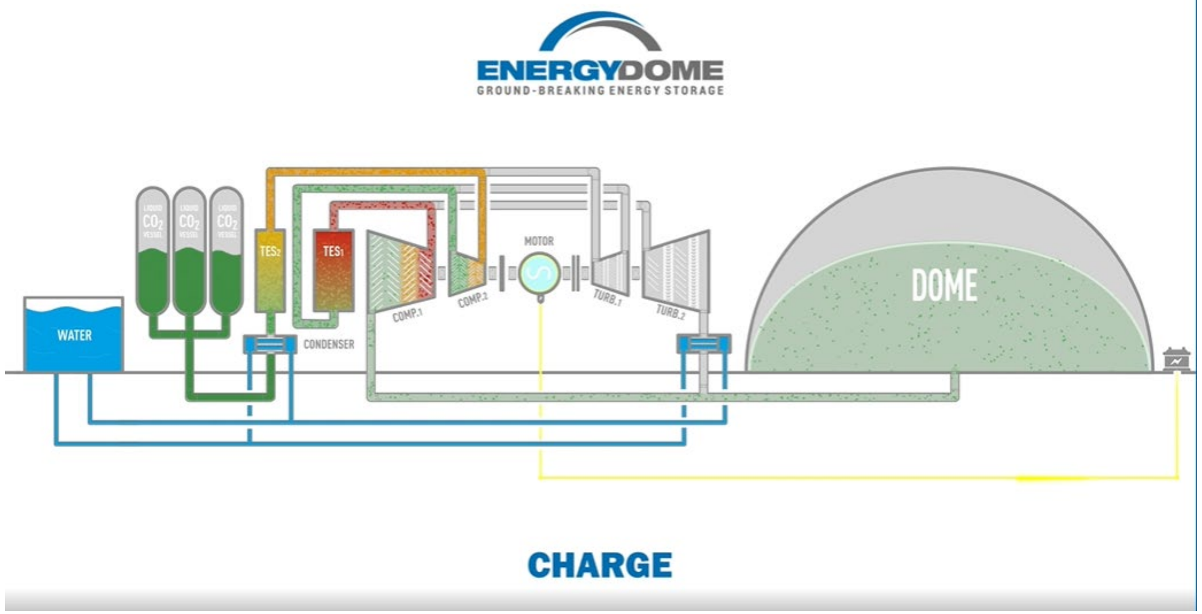
- Provides electricity, heating, and cooling on demand for variety of industries and buildings
- Targeting process industries, data centers, power producers, utilities, and large facilities
- Leverages HOFIM^{TM} hermetically sealed compressor
- Use ice for cold storage and hot water for hot stores
- Using hot and cold stores directly results in overall process efficiency up to 70%.



https://www.man-es.com/discover/a-tale-of-fire-and-ice

EnergyDome Liquid CO2 Storage

- Compresses CO2 from atmospheric pressure to pressure that can be liquified at ambient temperature (700-1000 psi, 48-69 bar)
- Heat of compressor stored as hot water
- Discharge cycle expands through reheat turbine
- Low pressure CO2 storage in large dome.
- Claim RTE>75%
- Not site dependent



https://energydome.it/co2-battery/

Oxygen Storage Incorporated into the Allam-Fetvedt SCO_2 Oxy-Fuel Direct-Fired Power Cycle

Technology Summary

- *Apply liquid oxygen (LOX) storage to a natural gas, direct-fired SCO_2 power cycle*
- *Air Separation Unit (ASU) operated during low LMP and at part-load during medium LMP*
- *LOX stored and utilized during high LMP*

Technology Impact

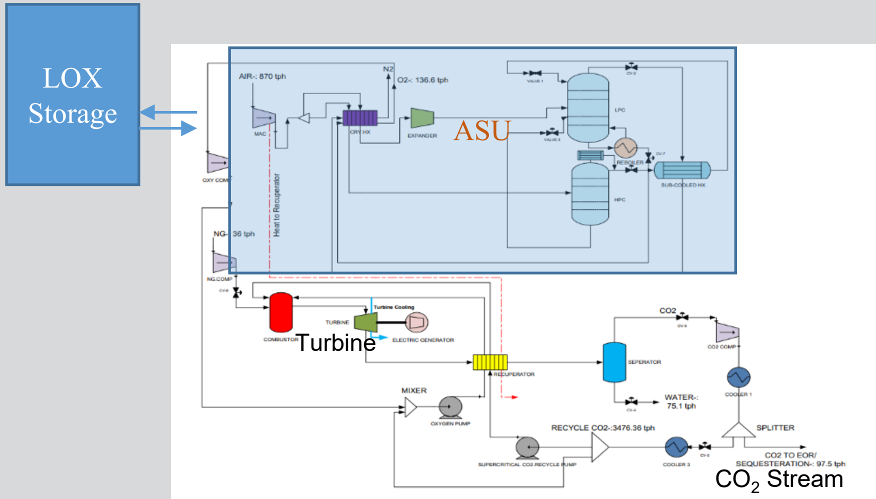
Provides up to 20% greater power plant output (with the same fuel burn) during high demand by reducing the parasitic load of the ASU while maintaining zero NOx and SOx emissions and producing pipeline quality CO_2

Proposed Targets

Metric	State of the Art	Proposed
	NGCC with CCS	*Allam Cycle with O2 Storage*
Operating Cost (Fuel) $/MWh-net	*$45.87 NGCC with CCS*	*$34.76 Allam Cycle with O2 Storage*
Net Plant Efficiency	50.6%	66.8% (ASU burden removed)

NetPower 50 MWt Pilot Plant

Air Liquide Liquid O_2 Storage

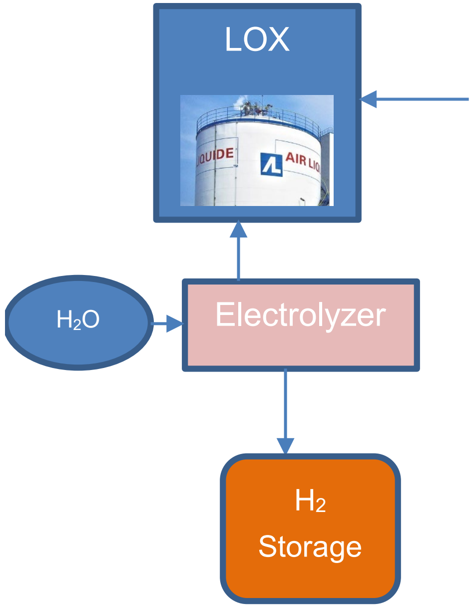


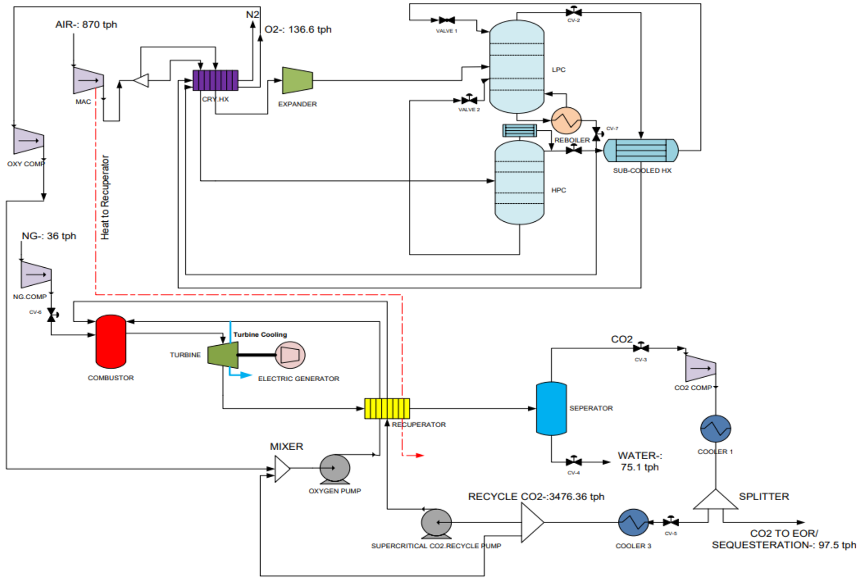
Allam-Fetvedt Cycle Incorporating Oxygen Storage

Carbon-free natural gas fired power generation with 20% less operating cost using liquid oxygen energy storage

Hydrogen and Oxygen Storage with Allam-Fetvedt Cycle

- High pressure electrolysis of generating both gaseous oxygen and hydrogen
- GOX liquified in ASU
- Hydrogen stored in vessels or underground
- For discharge, H2 mixed with natural gas and used in oxy-fuel cycle
- Awaiting funding to quantify RTE





Summary

- Unique power or energy storage cycles require unique equipment designs to implement them
- SCO2 power cycles showing good promise to improve cycle efficiencies
- High fluid density and low cycle pressure ratio greatly reduces equipment size for SCO2 cycles
- SCO2 cycles have application to energy storage for both thermochemical and pumped heat applications
- For the direct-fired Allam-Fetvedt cycle, both fuel (hydrogen) and oxidizer (LOX) may be used to store energy

Future SCO2 Research Needs

- Oxy-Fuel Combustion
- Hermetically sealed turbomachinery
- High temperature shaft end seals and bearings
- Compressor performance measurement
- Near-dome or in-dome compressor data
- Erosion/corrosion testing
- Dry gas seal reliability
- Transient HX measurements
- Transient model validation
- Leakage recovery/makeup options
- Oxy-combustion water/mixture chemistry and gas properties
- sCO2 mixture (for critical point tuning) gas property validation

Questions?

Jeff Moore, Ph.D.

jeff.moore@swri.org

210-522-5812