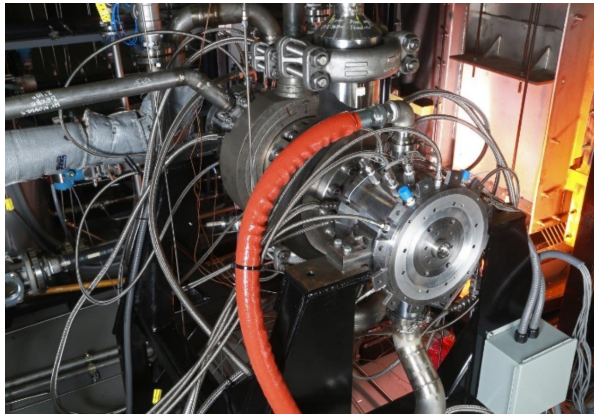
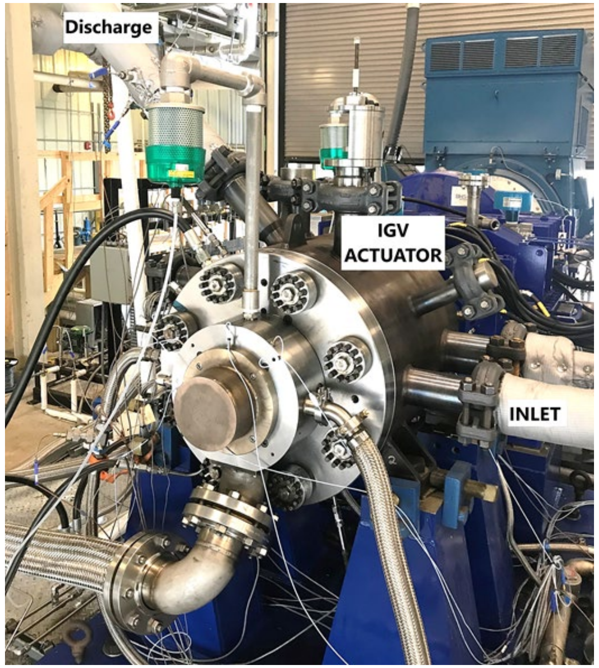
Status of sCO_2 Turbomachinery Development at SwRI





Jeff Moore, Ph.D.

Southwest Research Institute

7th International sCO2 Power Cycles Symposium

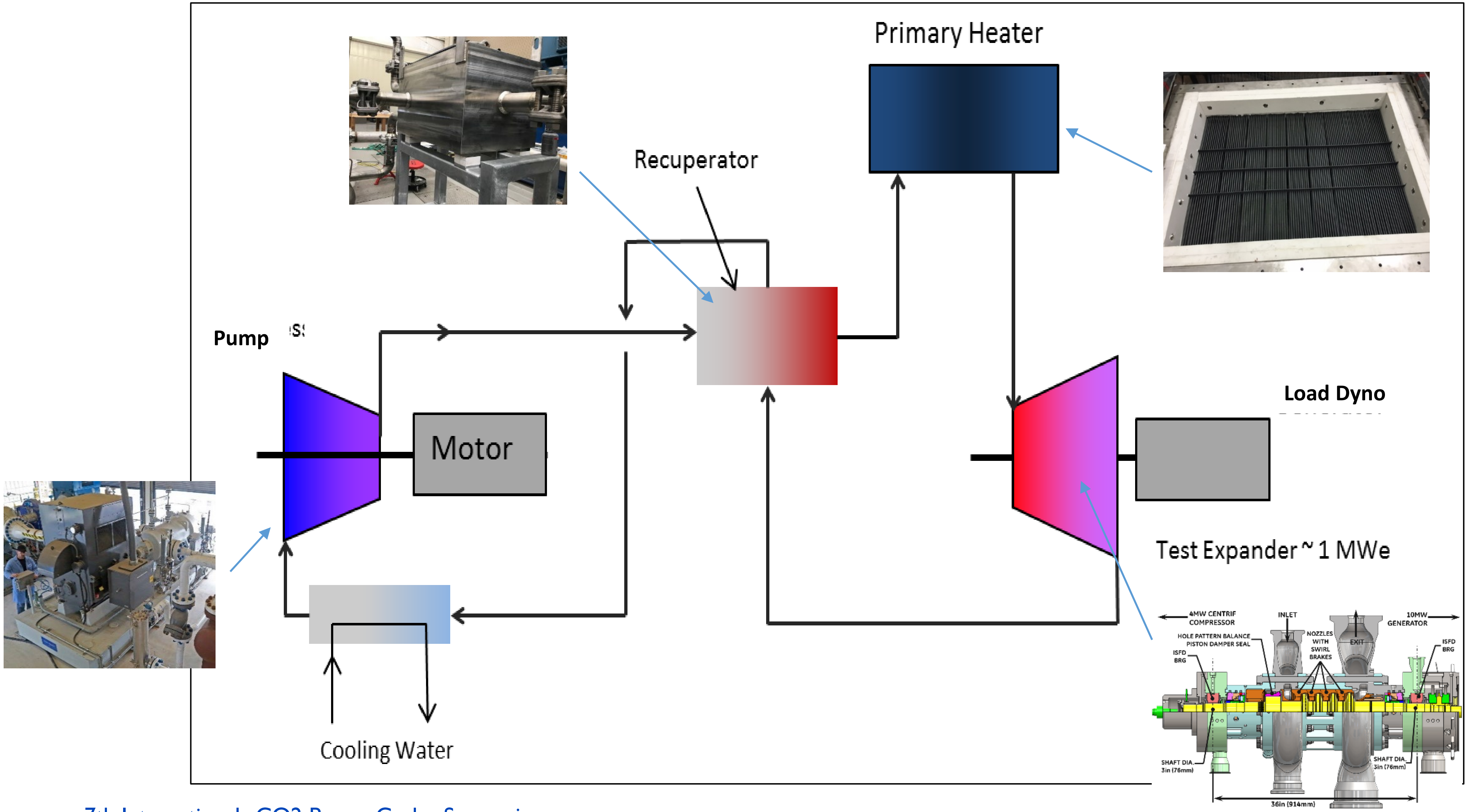
February 21-24, 2022

San Antonio, TX

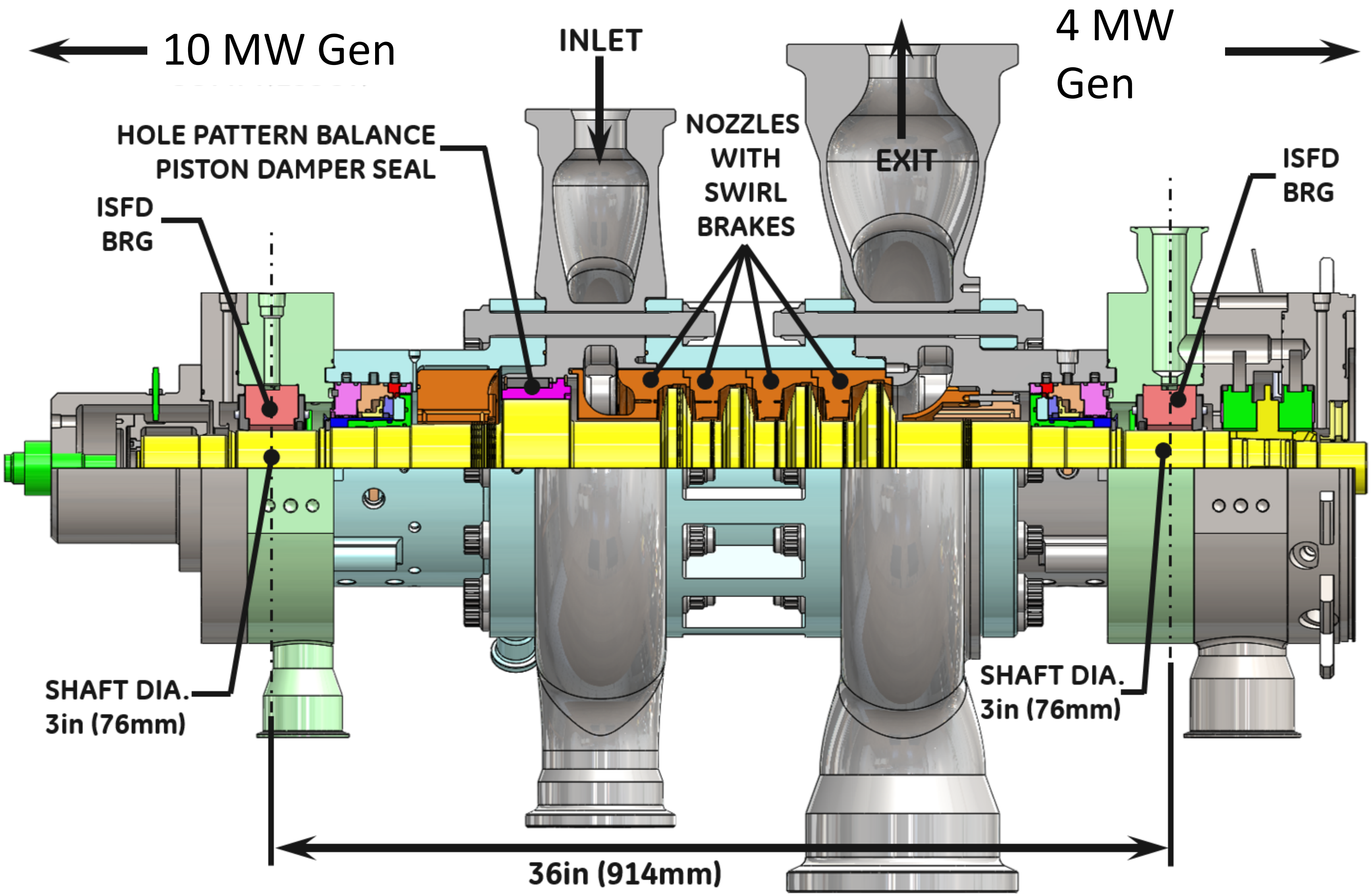
Sunshot Program (2013-2018)

- Develop and test 1 MW scale turbine and recuperator
- Partners: SwRI, General Electric GRC, Thar Energy, Aramco Services Co., Navy Nuclear Laboratory, and Electric Power Research Institute (EPRI)
- Developed 10 MWe Turbine Frame Size with 1 MW flow path
- Funded by EERE within US Dept. of Energy
- Completed Testing in Dec. 2018 Achieving Full Temperature (715C), Full Pressure (250 bar), and Full Speed (27,000 rpm)
- At the time, the Highest Temperature SCO2 Turbine in the Literature
- New cycle required development of new expander, compressor, and recuperator

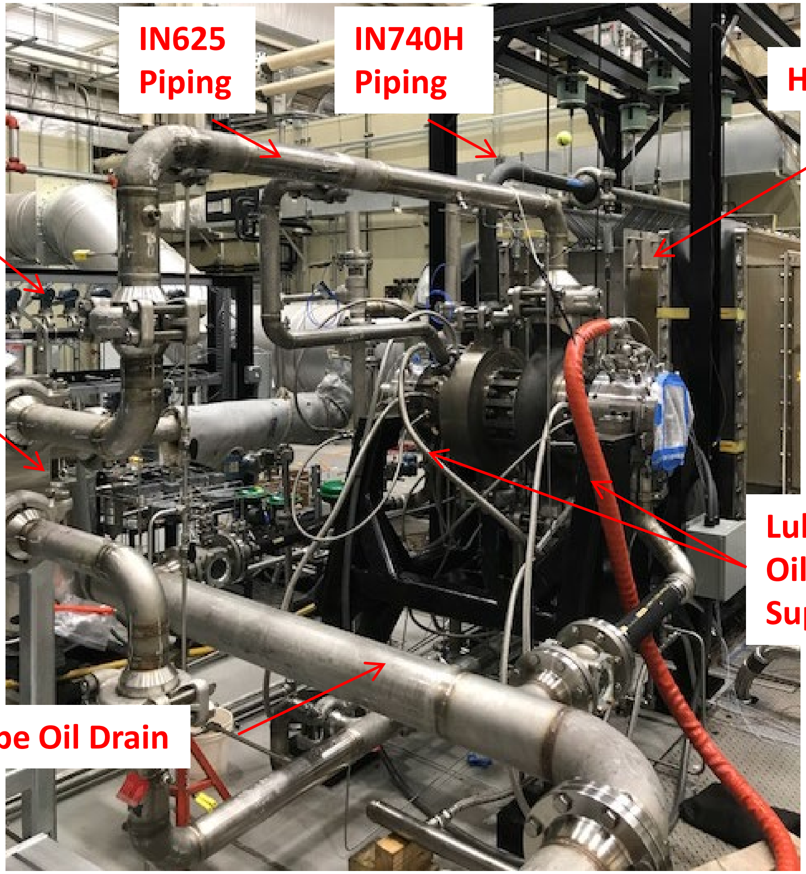
SUNSHOT: Simple sCO_2 Recuperated Cycle for Test Loop

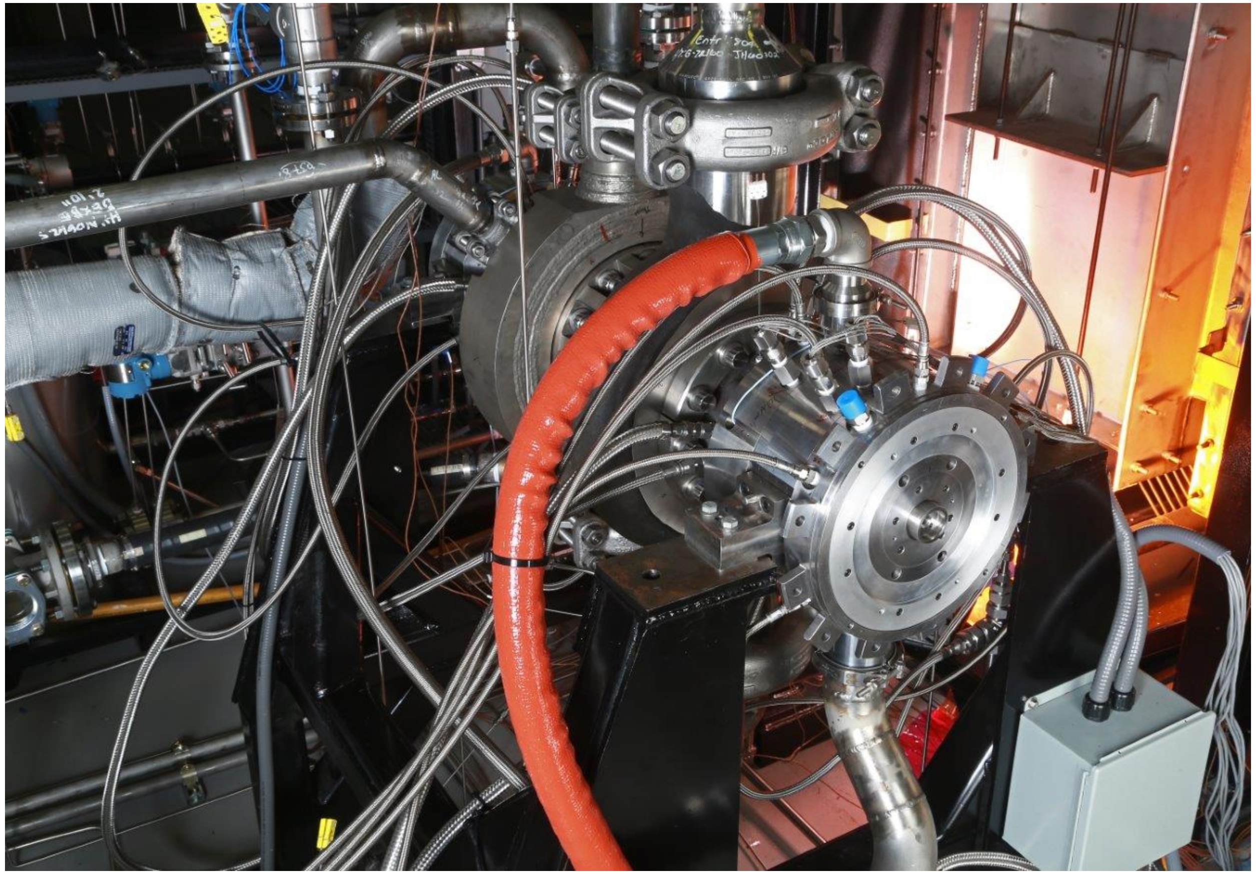


Sunshot Turbine Design



Sunshot Test Loop Components

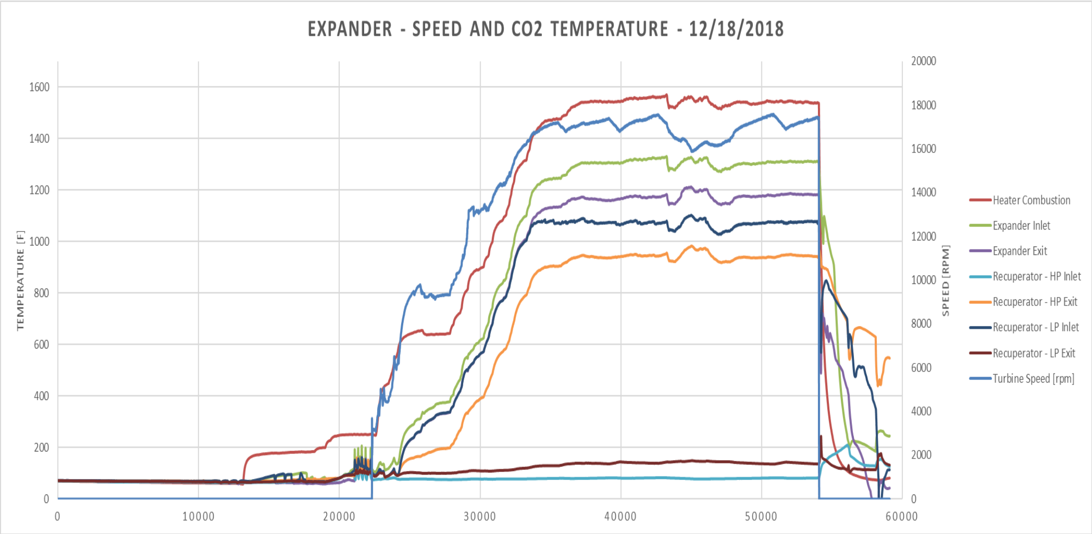




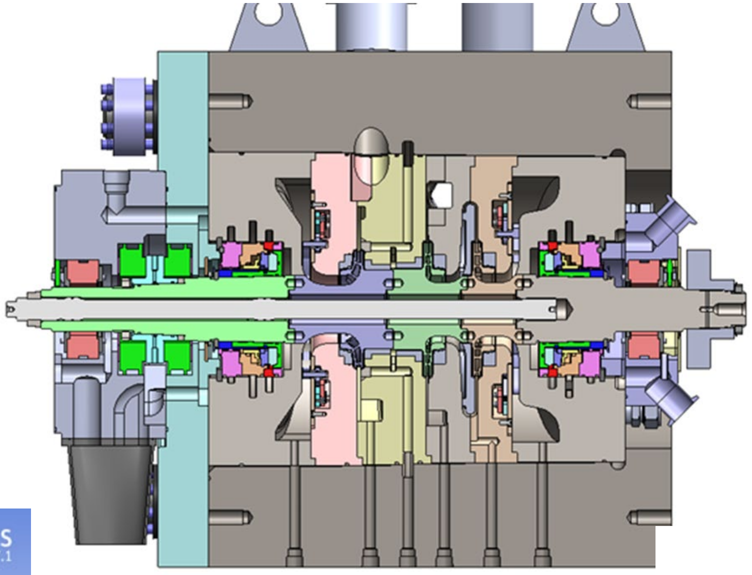
	Speed (rpm)	Turbine Inlet Temp. °C (°F)	Turbine Inlet Pressure bar (psi)	Turbine Exit Pressure bar (psi)
1st Design Point	21,000	550°C (1022°F)	~200 bar (3000 psi)	80 bar (1160 psi)
2nd Design Point	27,000	715°C (1319°F)	~250 bar (3625 psi)	80 bar (1160 psi)

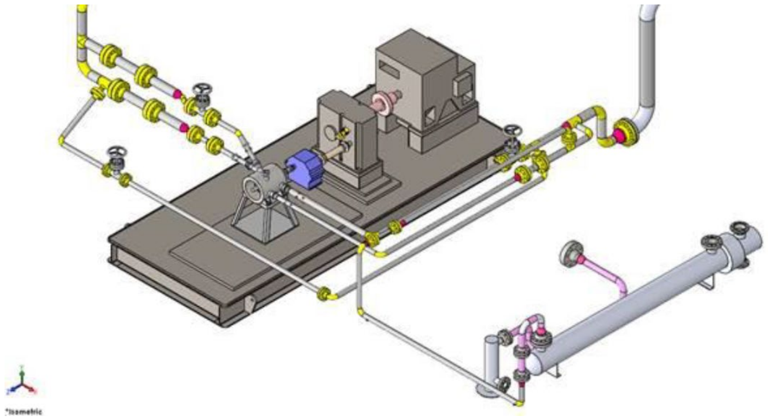
Loop Temperatures

6 Hour 715C Endurance Test

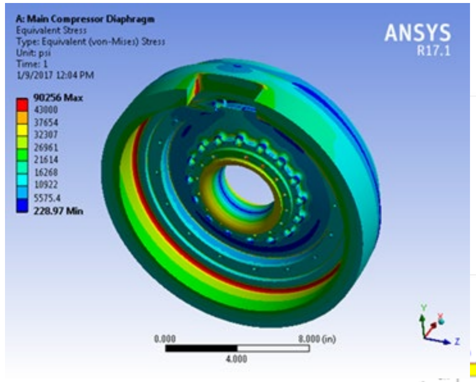


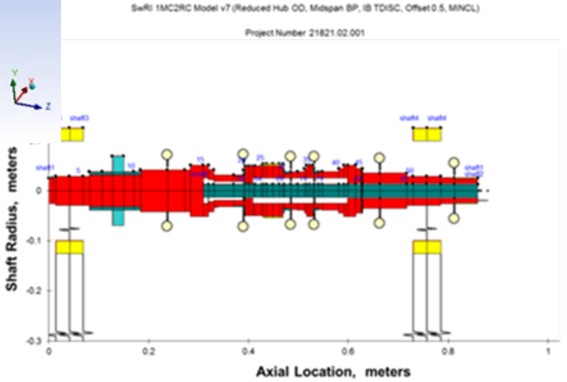
SwRI-GE-Apollo Compressor Design and Test Loop (2017-2021)

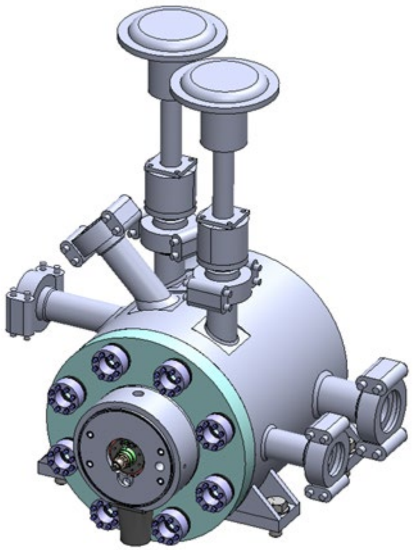


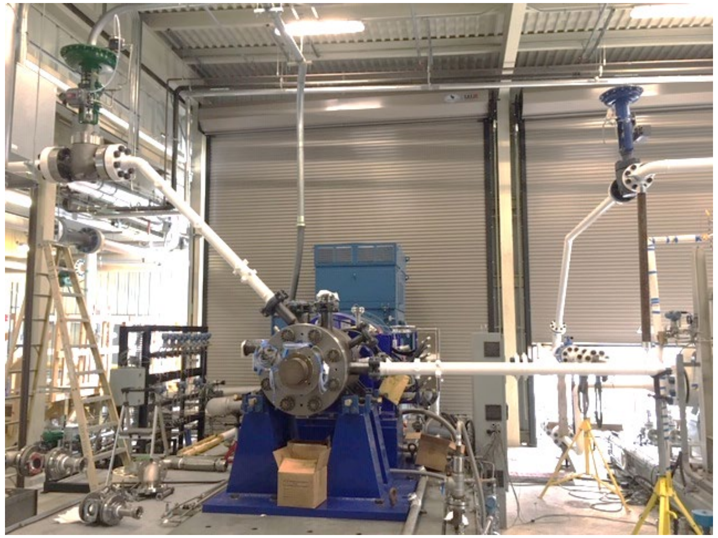


Southwest Research Institute (SwRI) sCO_2 Test Loop







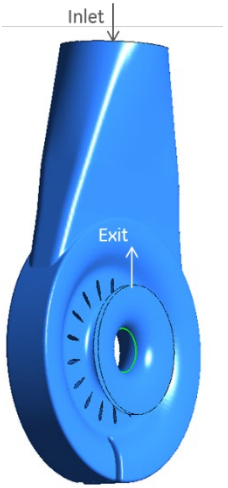


Testing has leveraged existing SwRI Sunshot loop with modifications

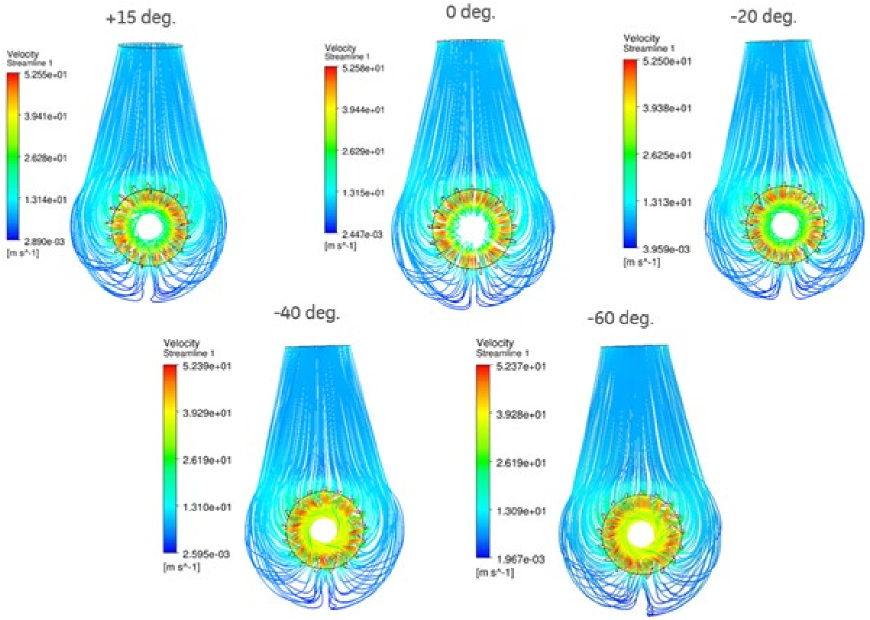
Apollo Compressor Design Goals & Challenges

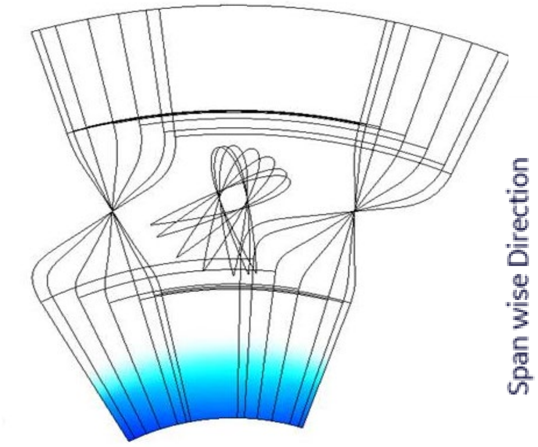
- Main compressor has very high pressure rise (2400 psi) and low head due to high inlet density
  - Requires high power, small diameter impeller
- Compressor casing that would be rated to 4,800 psia (25% above peak operating pressure)
  - Thick walls and large heads
  - Large retaining features (bolts or shear rings)
- Compressor package that included both Main and Bypass compressor that could be directly coupled to turbine for the sCO_2 power cycle
  - Longer rotor with large mass in middle of the shaft
  - High critical speed ratio of operation with high density flow
- Handle density swings up to 2X and flow ranges up to 3X
  - Meet target discharge pressure and mass flow over a wide range of suction pressures and temperatures
  - Requires flow control enhancement using Actuated IGVs
- Rotating speed of 27,000 rpm to match target turbine
  - High speed seals (same as Sunshot)
- Internal Bundle design
  - Ease of assembly / disassembly
  - Requires a tightly packaged system with many critical internal features

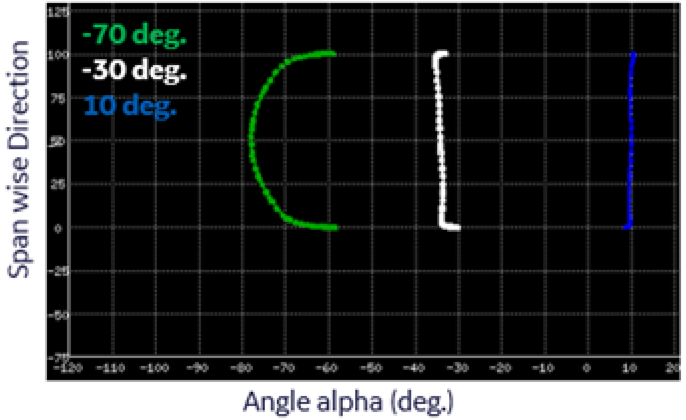
Variable IGV Design

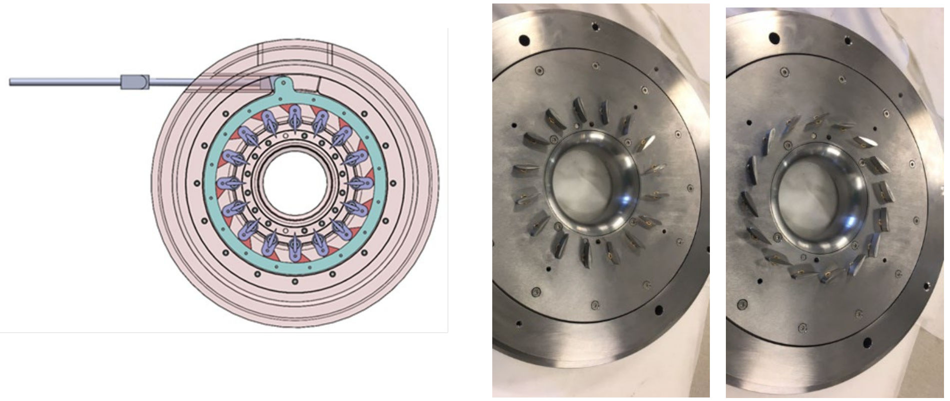


17 Radial IGVs in baseline design





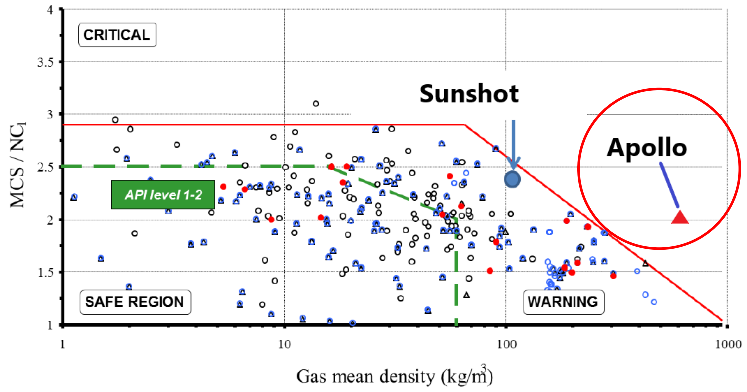


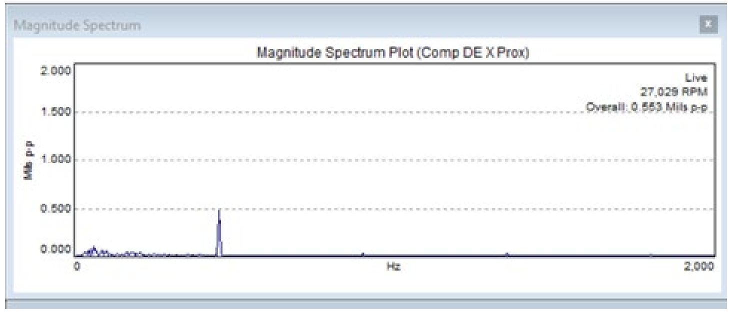


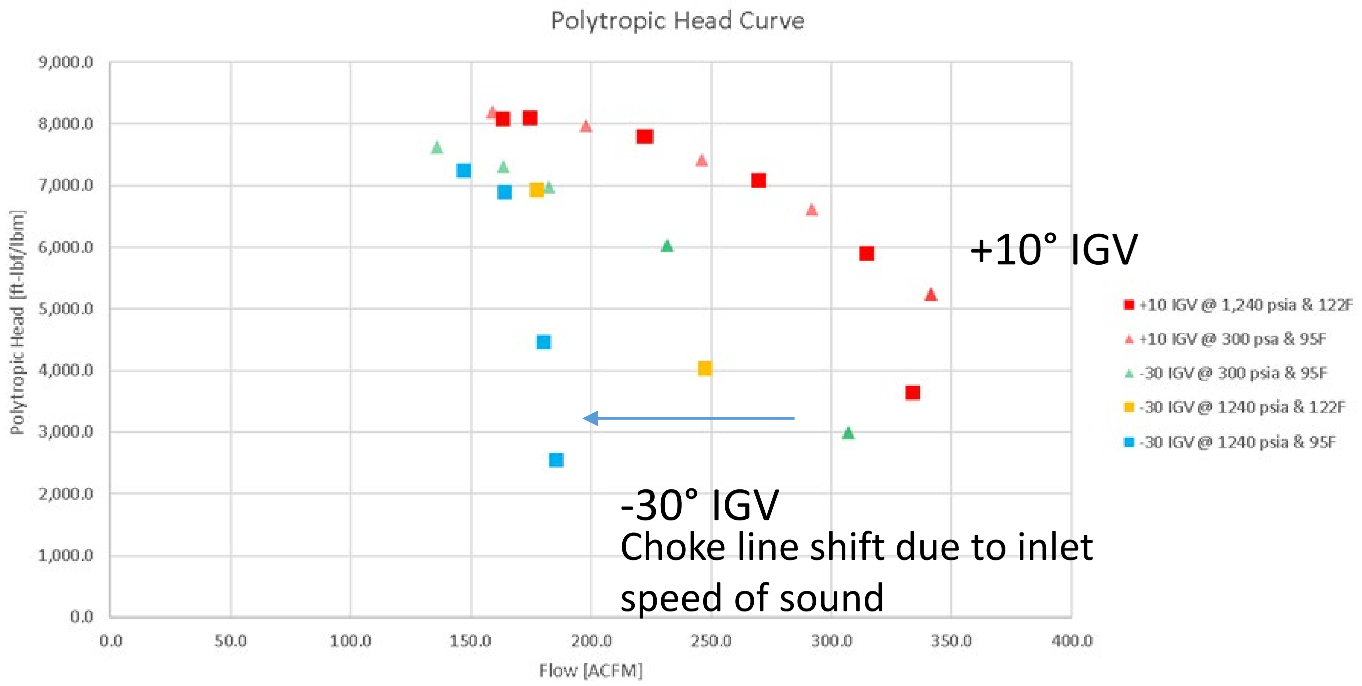
IGV Mechanism using external actuator

Test Data

- Rotordynamic stability a concern due to high fluid density
- Bearing modifications required to manage fluid induced forces due to high density by eliminating squeeze film dampers
- Performance data shows strong effect of inlet temperature



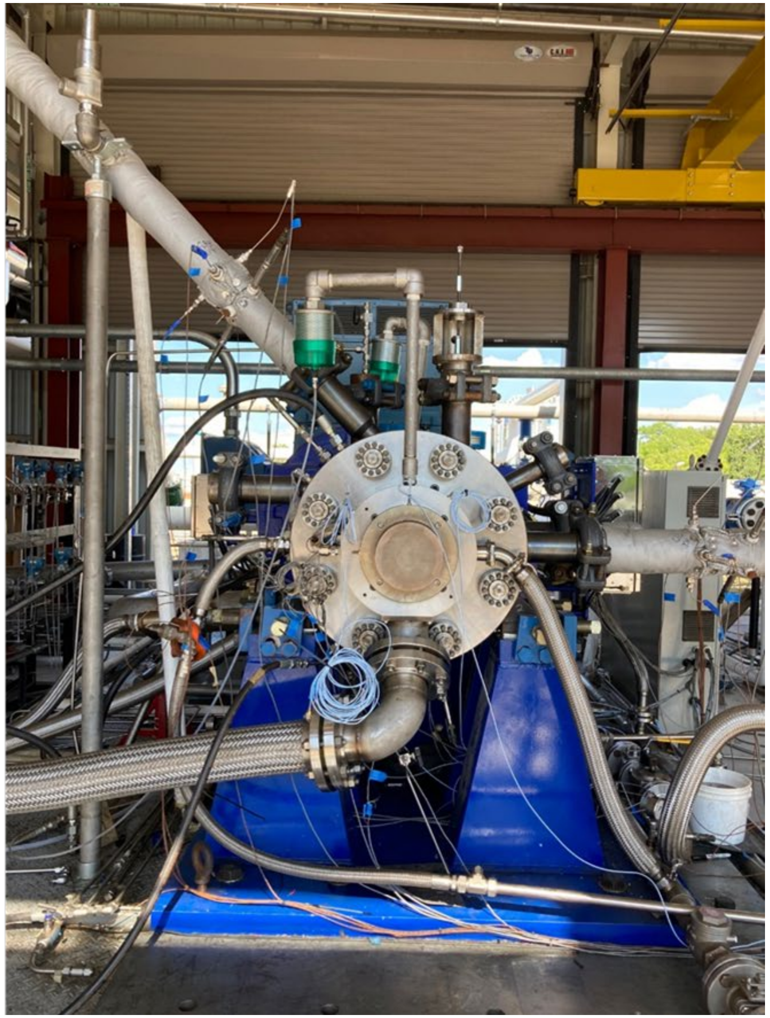




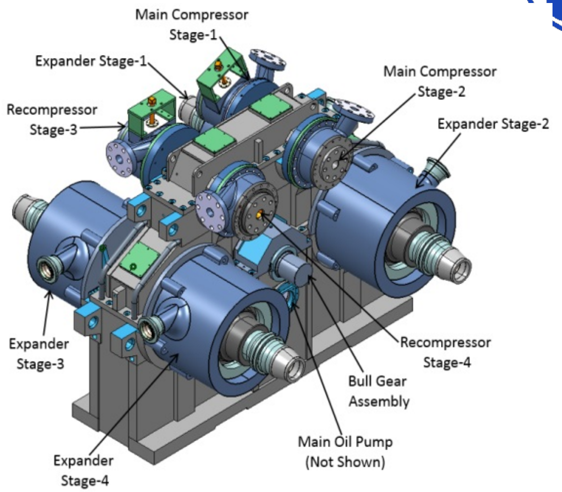
Apollo Compressor Testing

Notable Achievements:

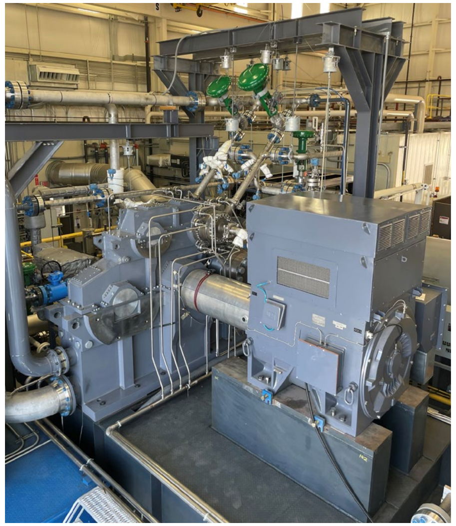
- **World Record density: 720 kg/m^3**
- Smallest impeller manufactured by BHGE.
- Mechanically well-behaved demonstrating high pressure CO_2 compression possible.
- Highlighted challenges with measuring CO2 properties near the liquid-vapor dome.



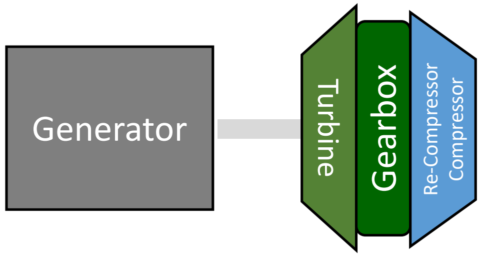
Ultra High Efficiency Integrally-Geared sCO2 Compander *(SwRI, Hanwha for DOE EERE) (2017-2021)*



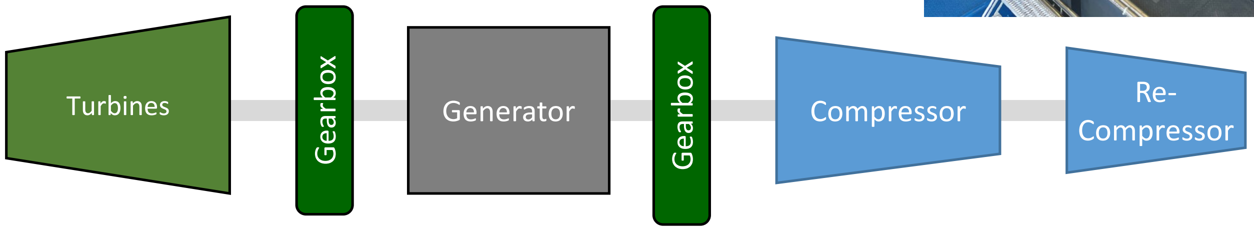
- Design a sCO2 integrally geared compander (IGC)
  - Combining compression and expansion stages into a single integrally geared housing connected to a low speed motor/generator.
- Benefits:
  - Reduced footprint
  - Potential cost reduction up to 35%
  - Utilizes a low speed commercially available driver/generator
  - Modular (Small Industrial [5MW] to Small Utility [50 MW])
  - High efficiency over a wide range of operating conditions
  - Improved cycle controllability
  - Reduced mechanical complexity ➔ improved reliability and reduced maintenance
- Achieved 720°C and full pressure with low vibrations



Typical IGC Package

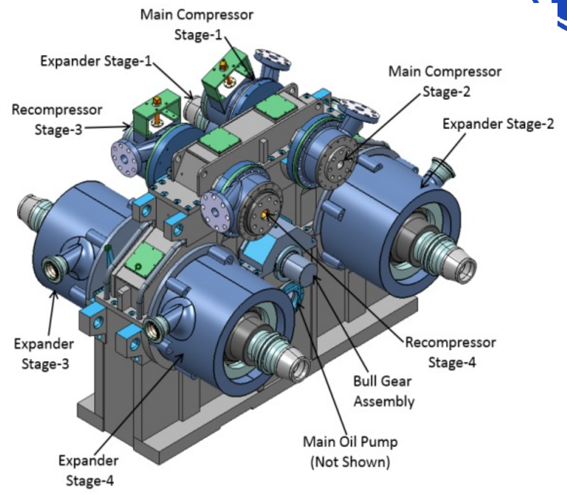


Conventional Turbomachinery Train

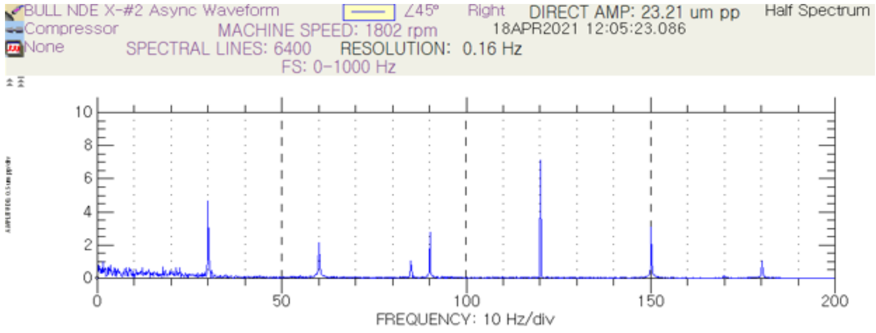


Ultra High Efficiency Integrally-Geared sCO2 Compander *(SwRI, Hanwha for DOE EERE) (2017-2021)*

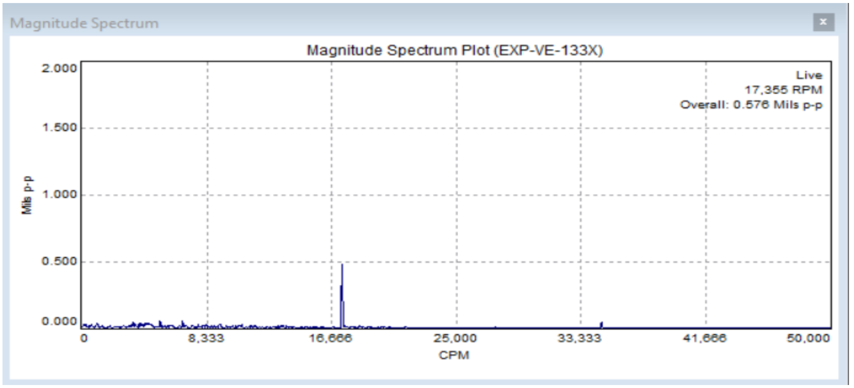
- Low vibration for bull gear and turbine pinion
  - Low subsynchronous vibration



Bull Gear

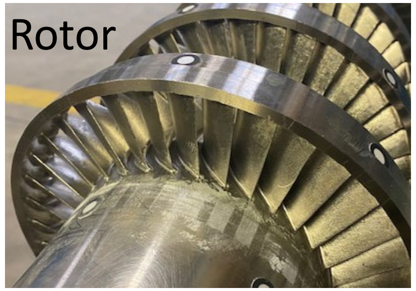


Turbine Pinion

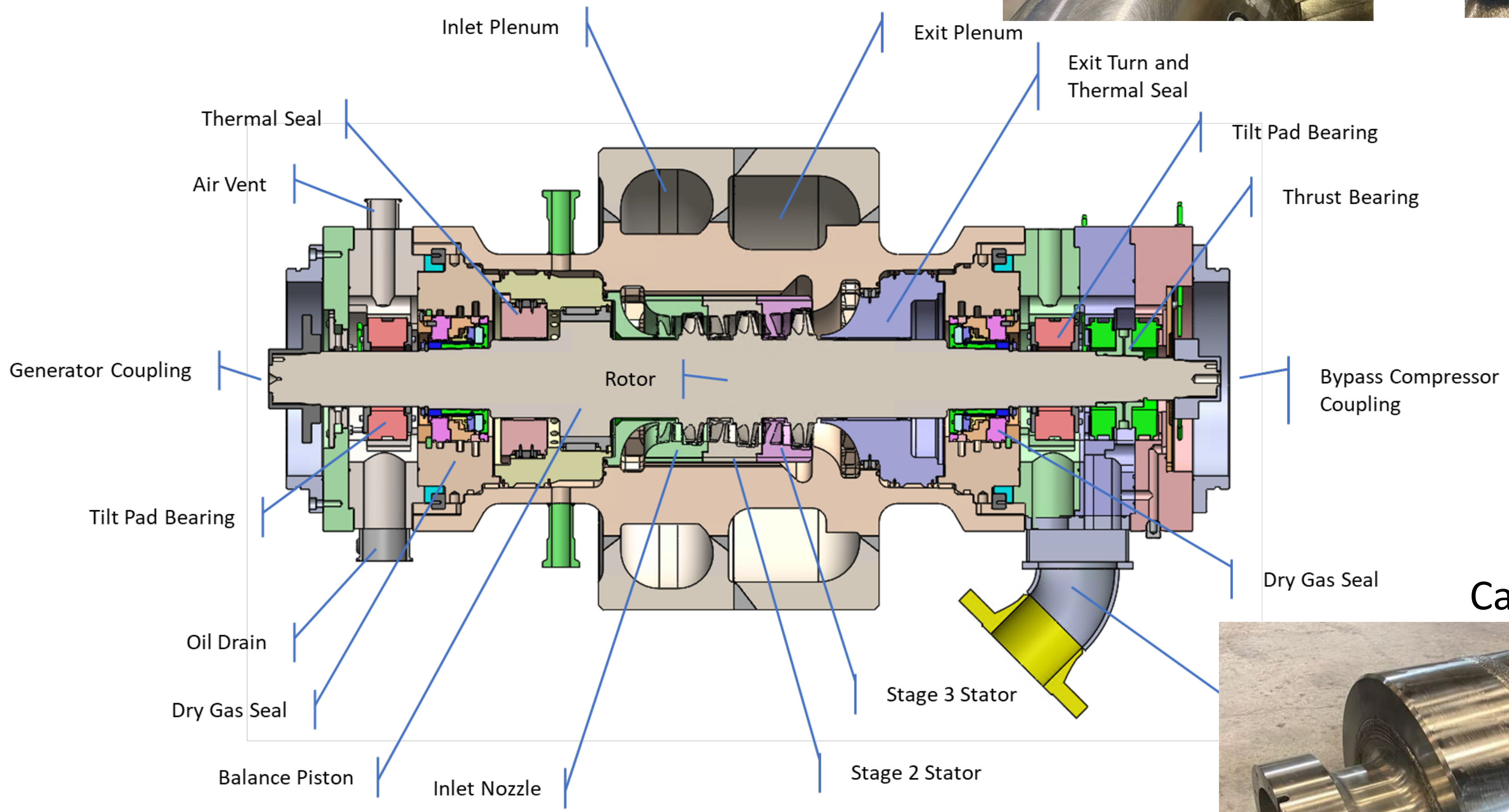


STEP 10 MWe Turbine

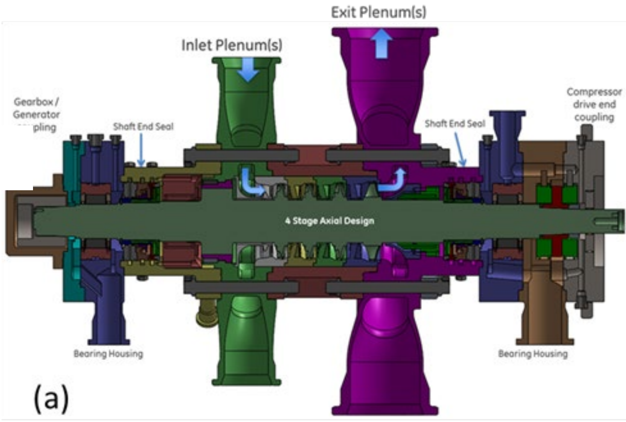
Monolithic Rotor and Stators



Stator Nozzle



Sunshot Turbine

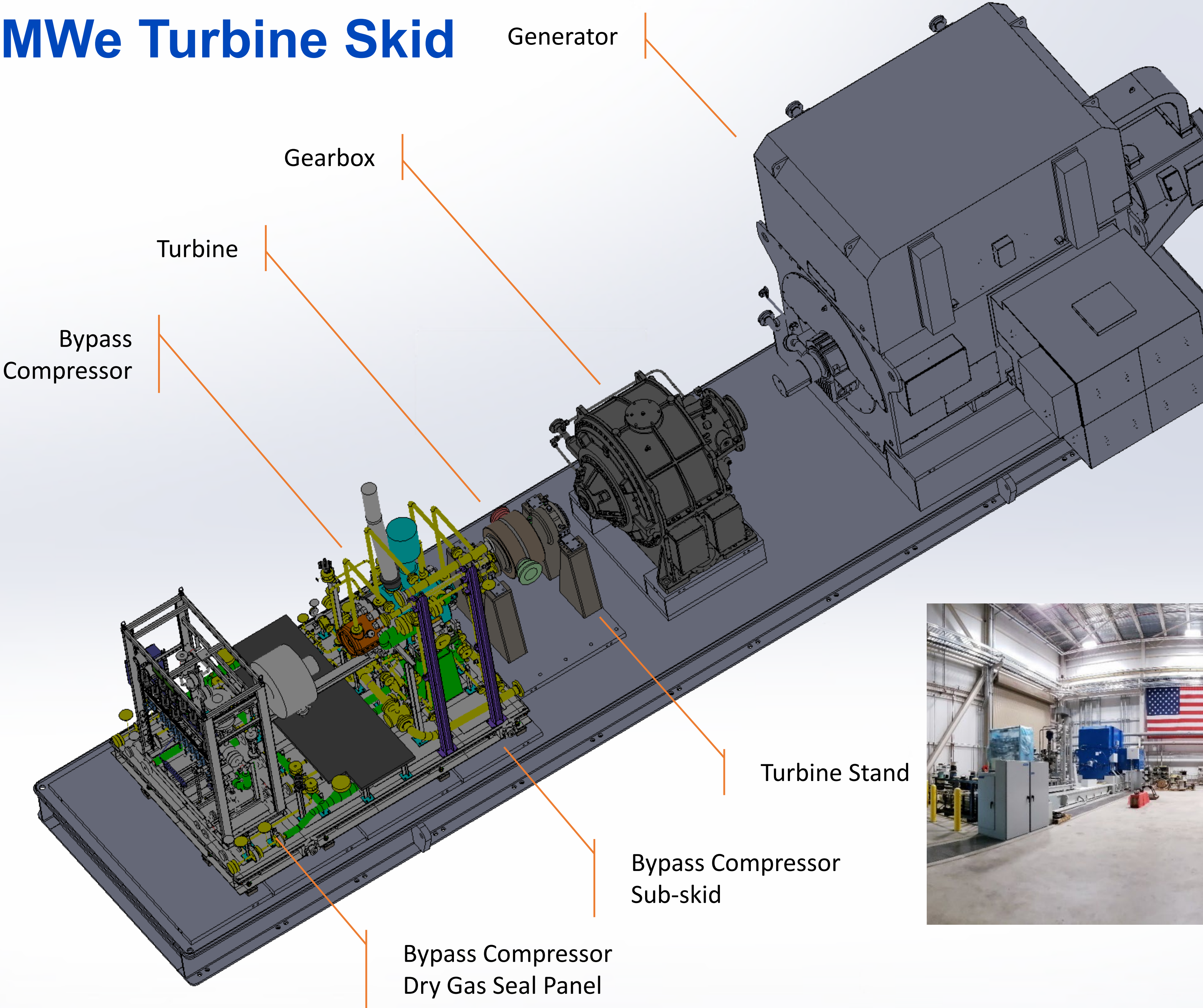


Casing

1-Piece Fabricated Inconel Casing

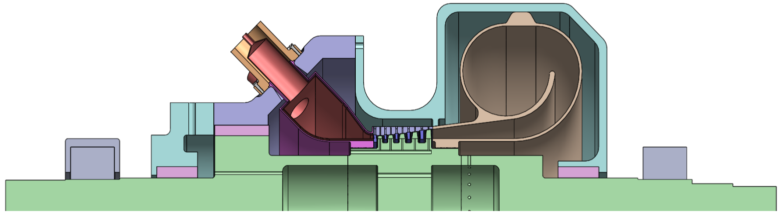
- Sunshot was Design Basis
- Monolithic Fabricated Case
- Same One-Piece Rotor
- Similar bearing and dry gas seal design
- 3 vs. 4 stages

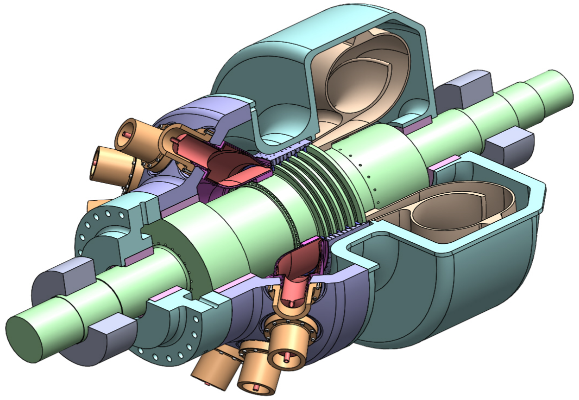
STEP 10 MWe Turbine Skid

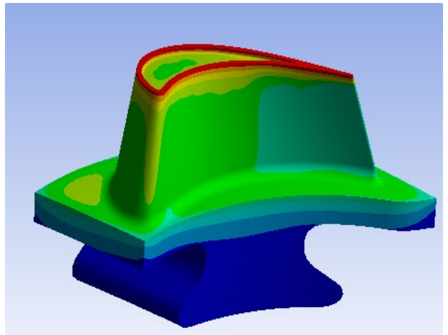


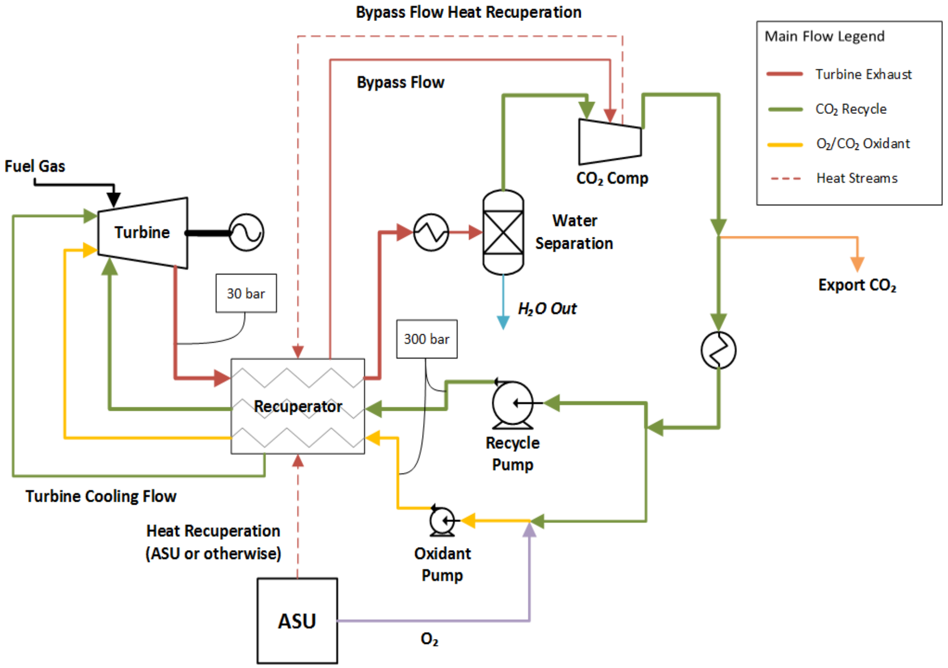
Direct-Fired Oxy-Fuel Turbine Development

- Developing a 300 MWe Utility Scale Oxy-Fuel Turbine with 1150 °C turbine inlet temperature at 300 bar using Allam-Fetvedt cycle
- Significantly improve the state-of-the-art for thermal efficiency (approaching 60%) and results in a high-pressure stream of CO_2 simplifying carbon capture, making the power plant emission-free.
- Funded under the DOE 21st Century CT program further developing oxy-fuel turbine design and performing material, combustion kinetics, and heat transfer testing for both natural gas and coal syn-gas.









Summary

- 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

Questions?

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