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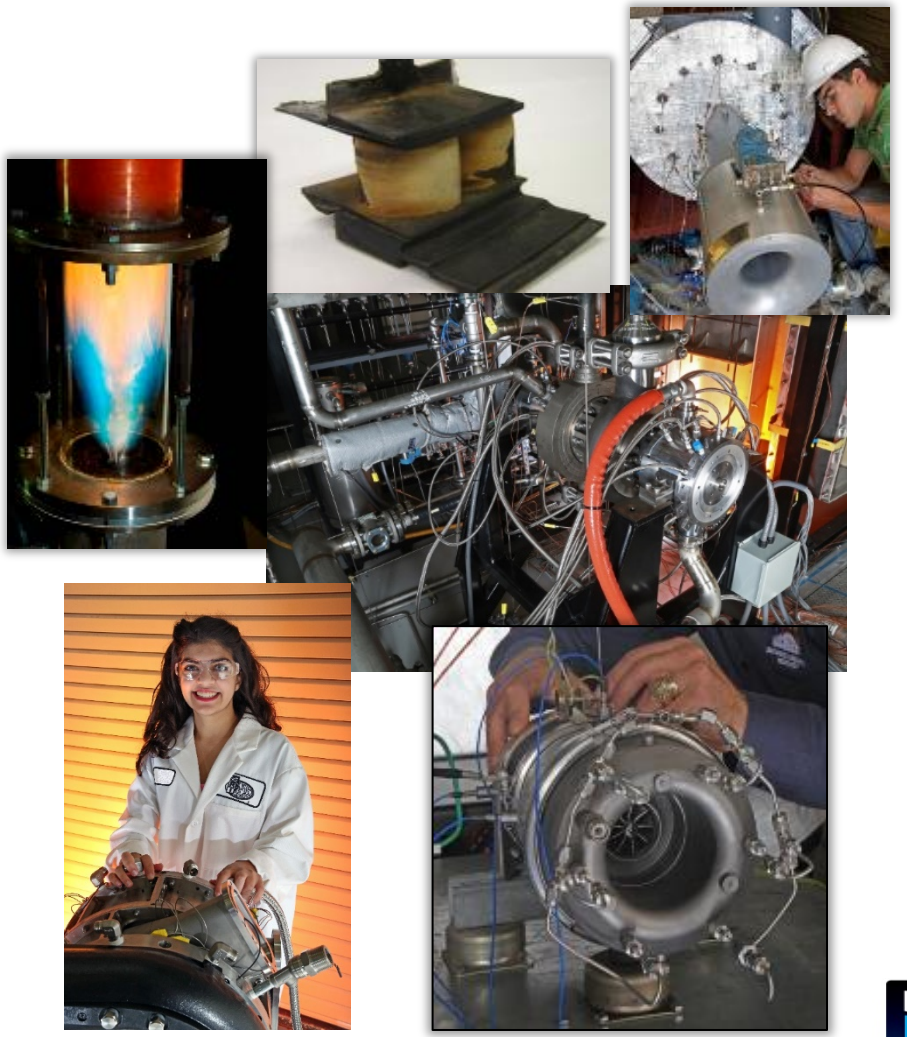
sCO_2 Development at Southwest Research Institute

Stefan D. Cich

Southwest Research Institute

- Founded in 1947, 2500 employees
- Machinery Department
  - Mechanical Engineering Division Focus on applied engineering research and development
  - Design, Fabrication, and Testing
- Specialties
  - Turbomachinery design and testing
  - Root cause failure analysis
  - Rotordynamic design/audit
  - Pipeline/plant simulation
  - CFD and FEA analysis
  - Test stand design
  - Performance testing
  - Thermodynamic cycles analysis
- Active DOE Programs in
  - Power Generation
  - Energy Storage
  - Renewable Energy
  - Improved Fossil Energy



Supercritical CO2 Cycle Applications

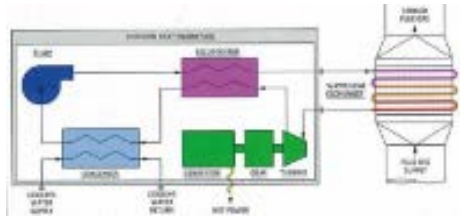
Primary Power
- High grade heat
- Optimized for system efficiency
- 0.3-2000 MWe

Concentrating Solar Power

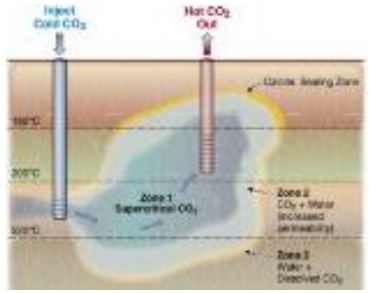
Fossil Fuel

Nuclear

Bottoming Cycles
- Low grade heat
- Optimized for net power
- 2-10 MWe

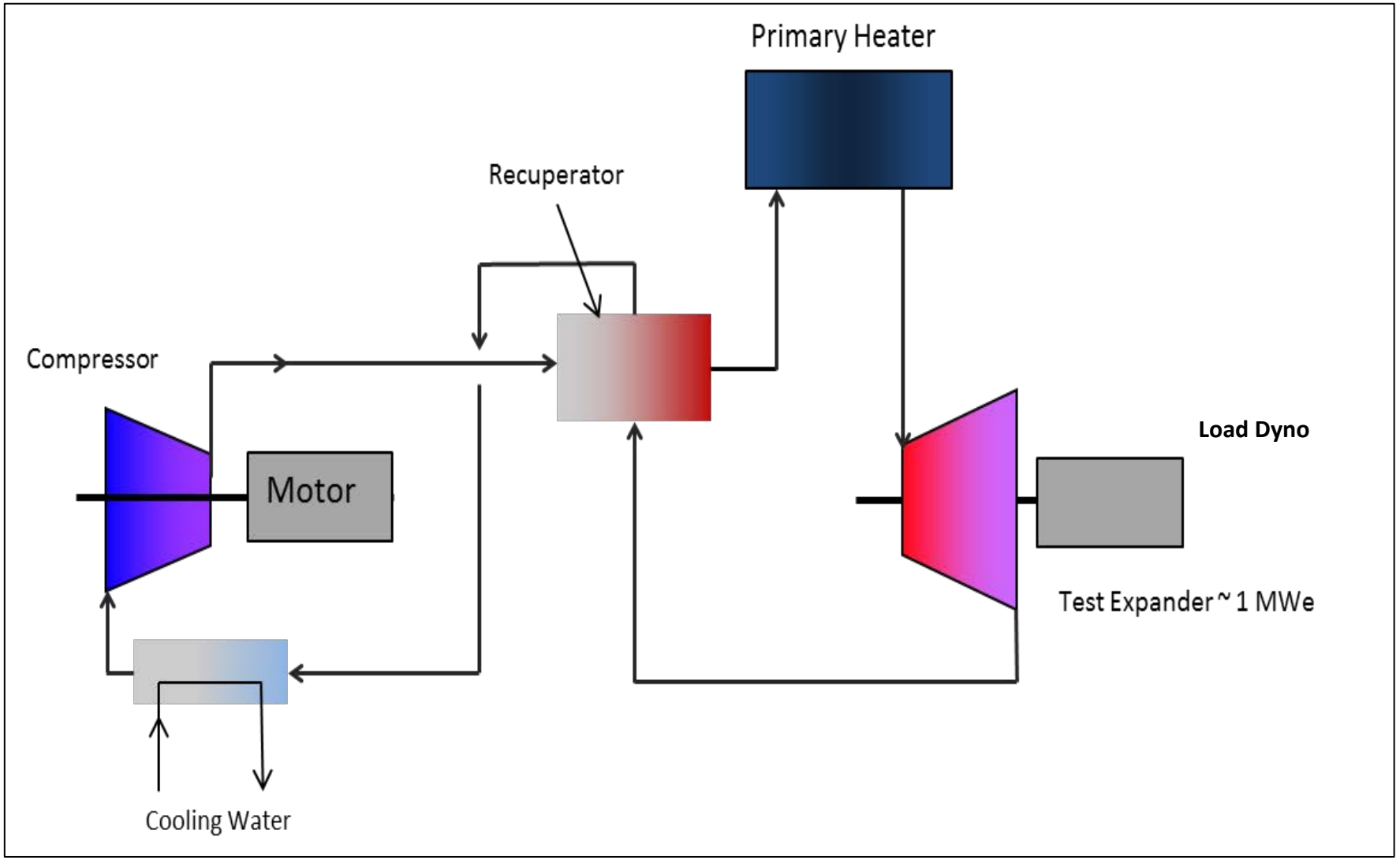


Waste Heat Recovery

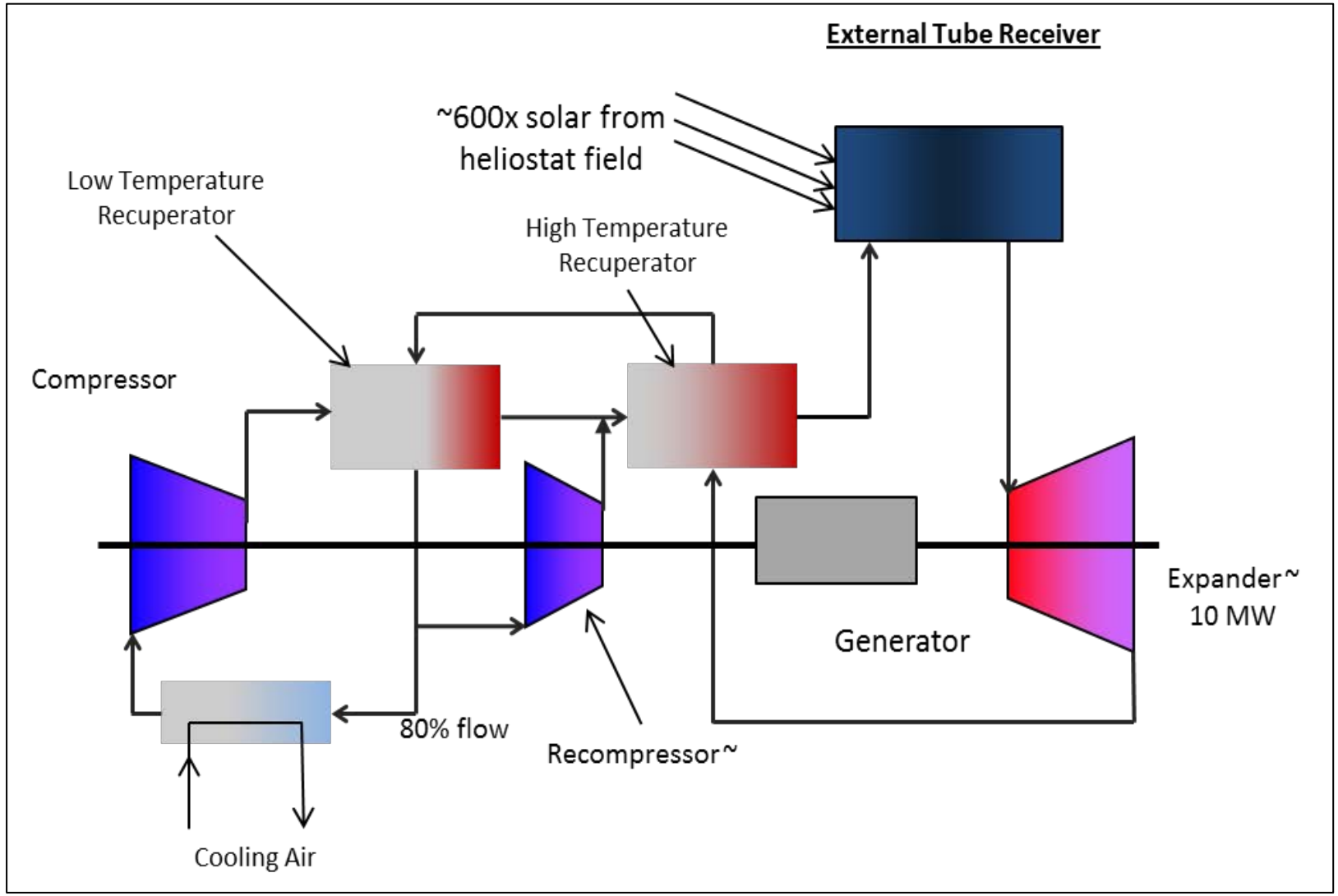


Geothermal

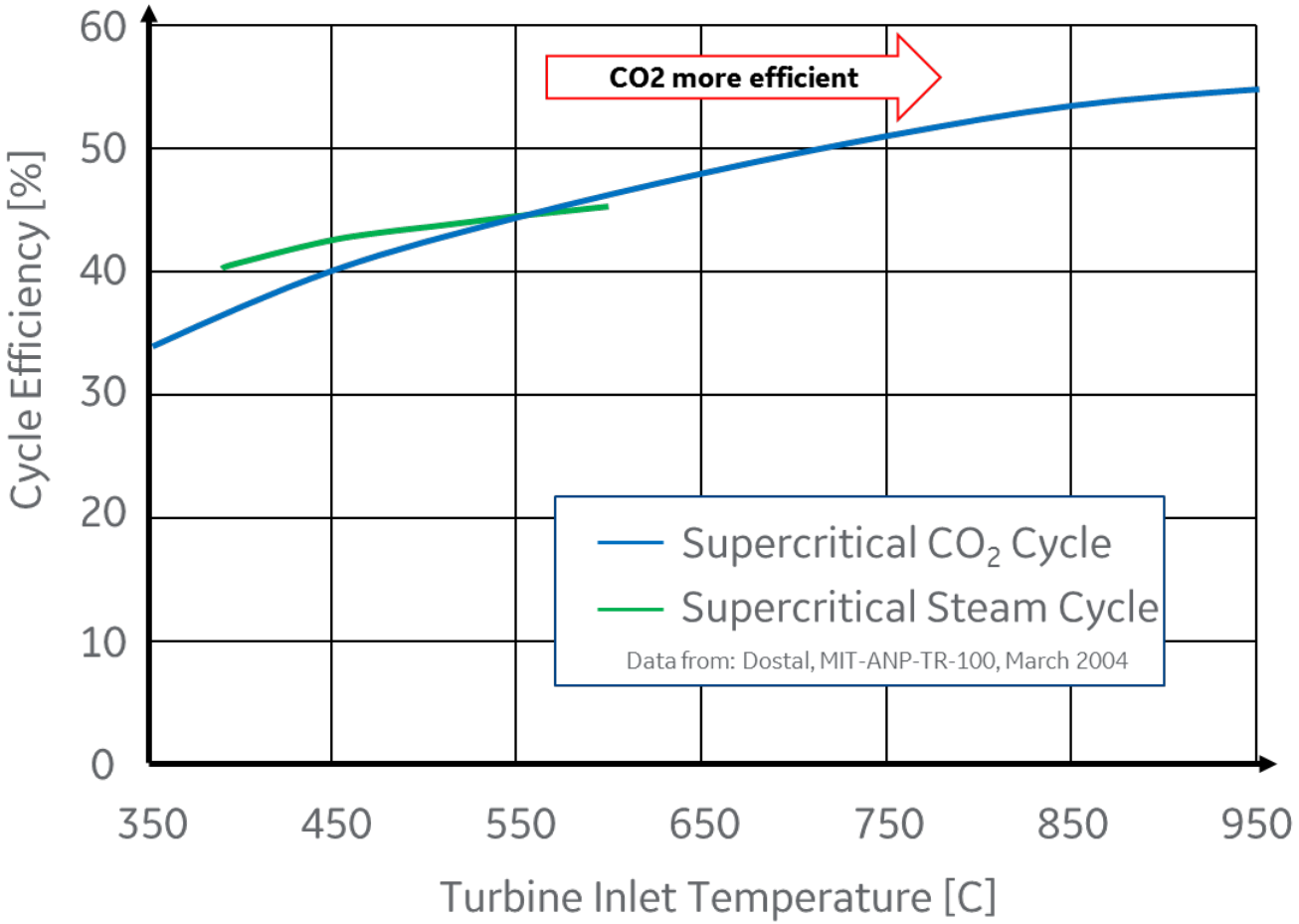
Simple sCO_2 Recuperated Cycle



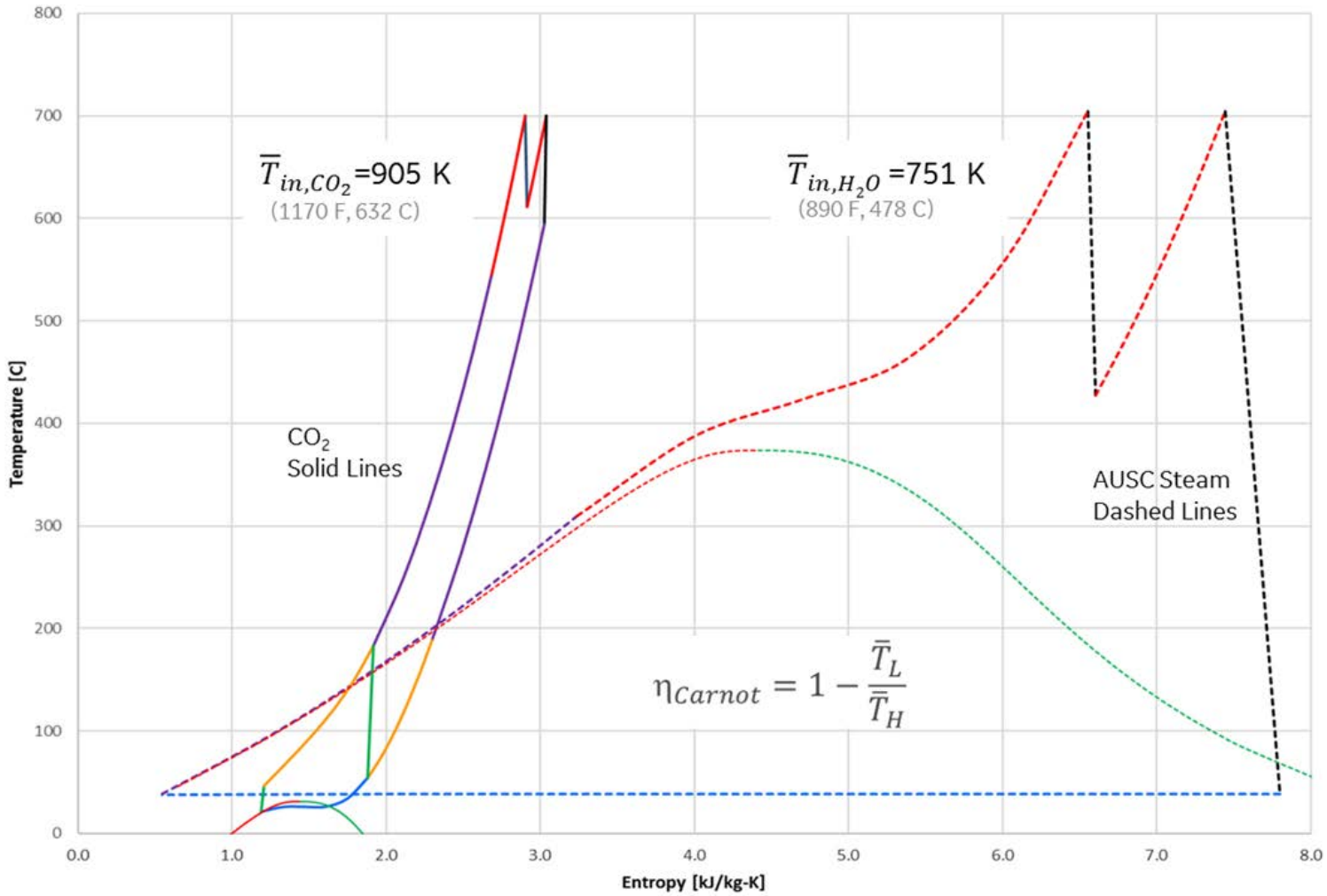
Recompression sCO_2 Cycle



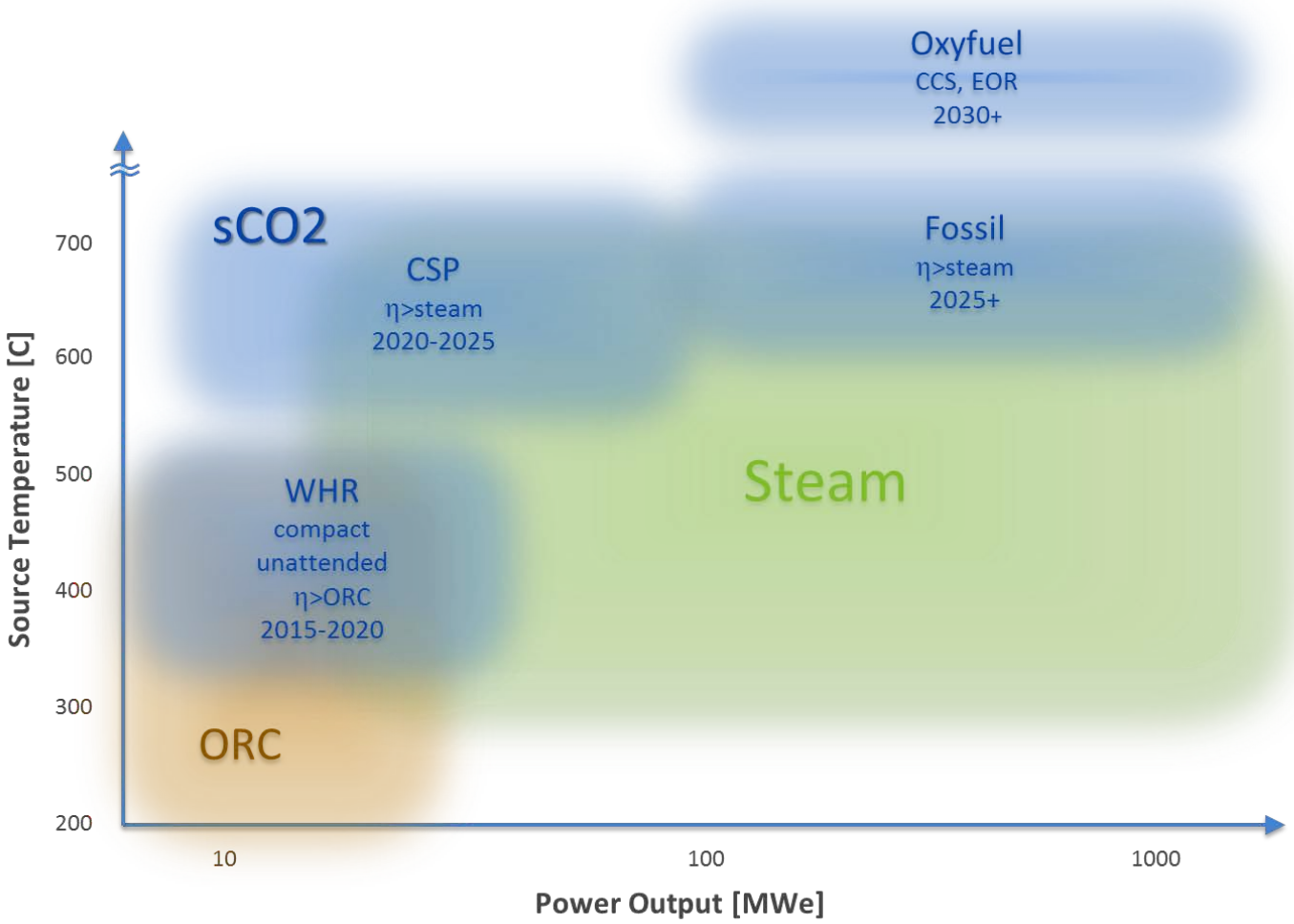
Transformation sCO_2 cycle defines a new curve



How it works – thermodynamic benefit

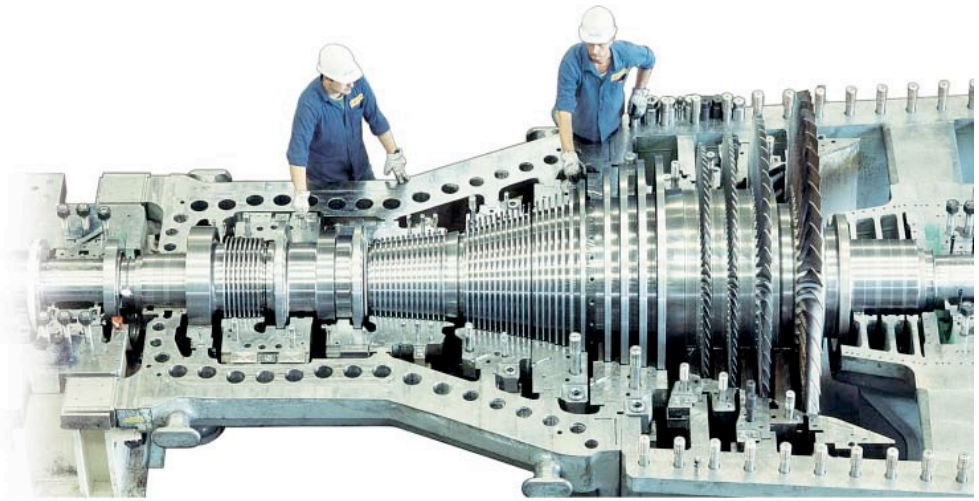


sCO_2 Power Gen Application Space



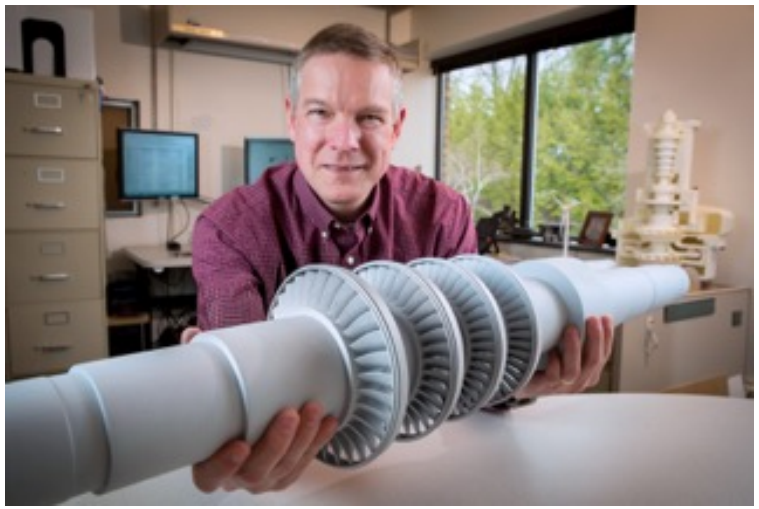
Smaller Turbomachinery

20 MW Steam Turbine



15 MW sCO_2 Turbine

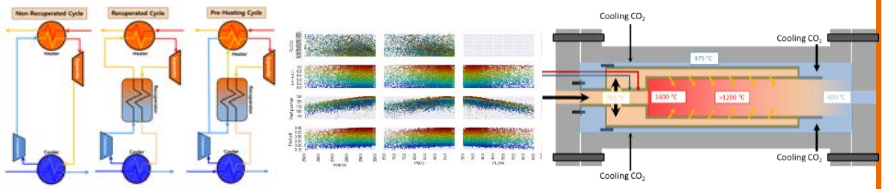
- 150 lb rotor, 7” dia, 27,000 RPM



SwRI sCO2 Technology Focus Areas

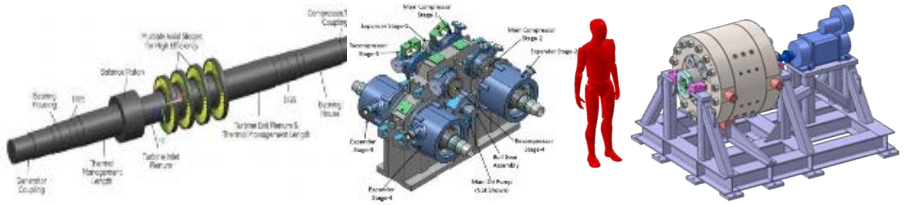
System and Cycles

- Design and evaluation for primary power and waste heat recovery
- Oxy-combustion component and system design and test
- System optimization with machinery design and component selection



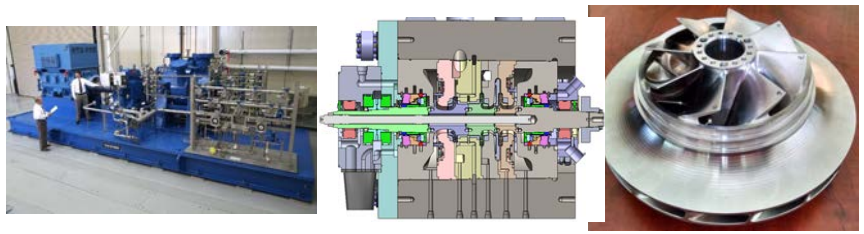
Turbines

- Component development and demonstration – Bearings, Seals
- Radial and axial flowpath machines
- Machinery design and rotordynamics



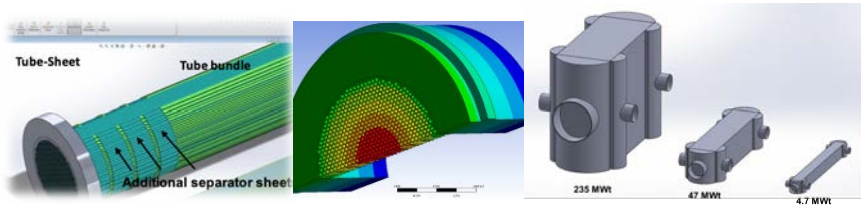
Compressors

- Flowpath design and simulation
- Machinery design and rotordynamics
- Machinery performance testing



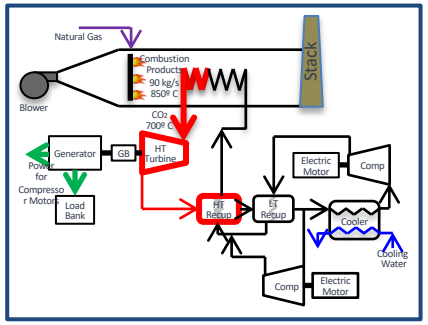
Heat Exchangers

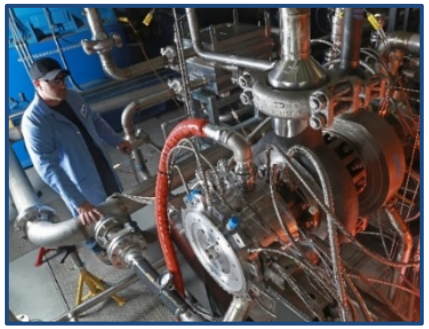
- Design and optimization for cost, performance, and manufacturing
- Simulation including CFD, FEA, and CHT

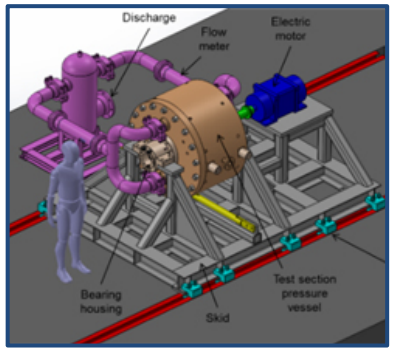


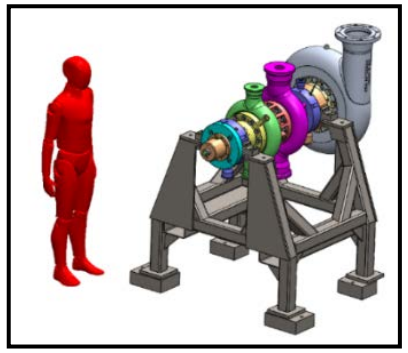
Progressing to Pilot Scale Demonstration

Individual Cycle and Component Development



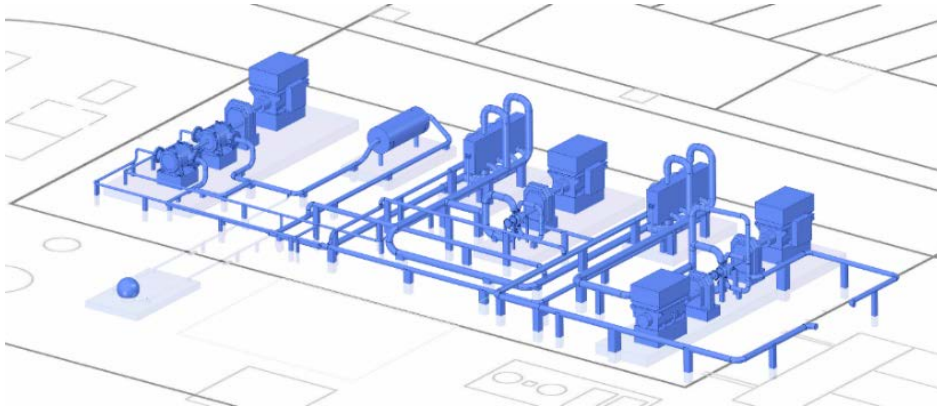






Leveraging $60 million in DOE investments into sCO_2 technology development

Integrated Pilot Scale System Demonstration



- Demonstrate sCO_2 system operability
- Verify component performance
- Show the potential for lower cost of electricity and high thermodynamic efficiency

Supercritical Transformational Electric Power (STEP) Program

Scope: Design, construct, commission, and operate a 10 MWe sCO_2 Pilot Plant Test Facility

Goal: Advance state of the art for high temperature sCO_2 power cycle performance from Proof of Concept (TRL3) to System Prototype validated in an operational system (TRL7)

Team: Gas Technology Institute (GTI)
Southwest Research Institute® (SwRI®)
General Electric Global Research (GE-GR)
U.S. Department of Energy (NETL)

Schedule: Three budget phases over six years (2016-2022)

Cost: $119MM Total / $84MM Federal Funding

Building a flexible platform for long-term use to validate component performance, quantify cycle efficiency, and study plant operability in an integrated, grid-connected system.

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Supercritical Transformational Electric Power (STEP) Program

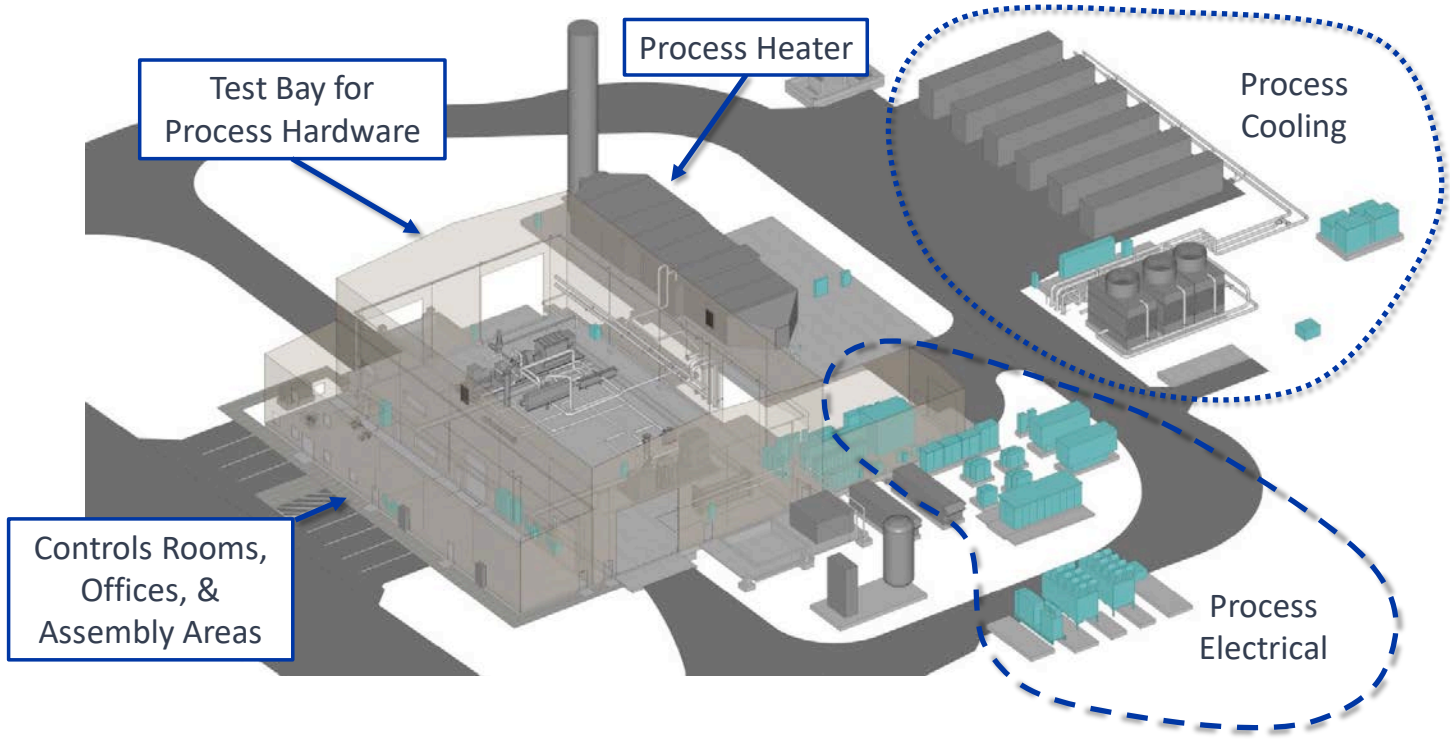
Demonstrate pathway to RCBC cycle efficiency > 50%

Demonstrate cycle operability up to 700°C turbine inlet temperature and 10 MWe net power generation

Quantify performance benefits:

- 2-5% point net plant efficiency improvement
- 3-4% reduction in LCOE
- Reduced emissions, fuel, and water usage

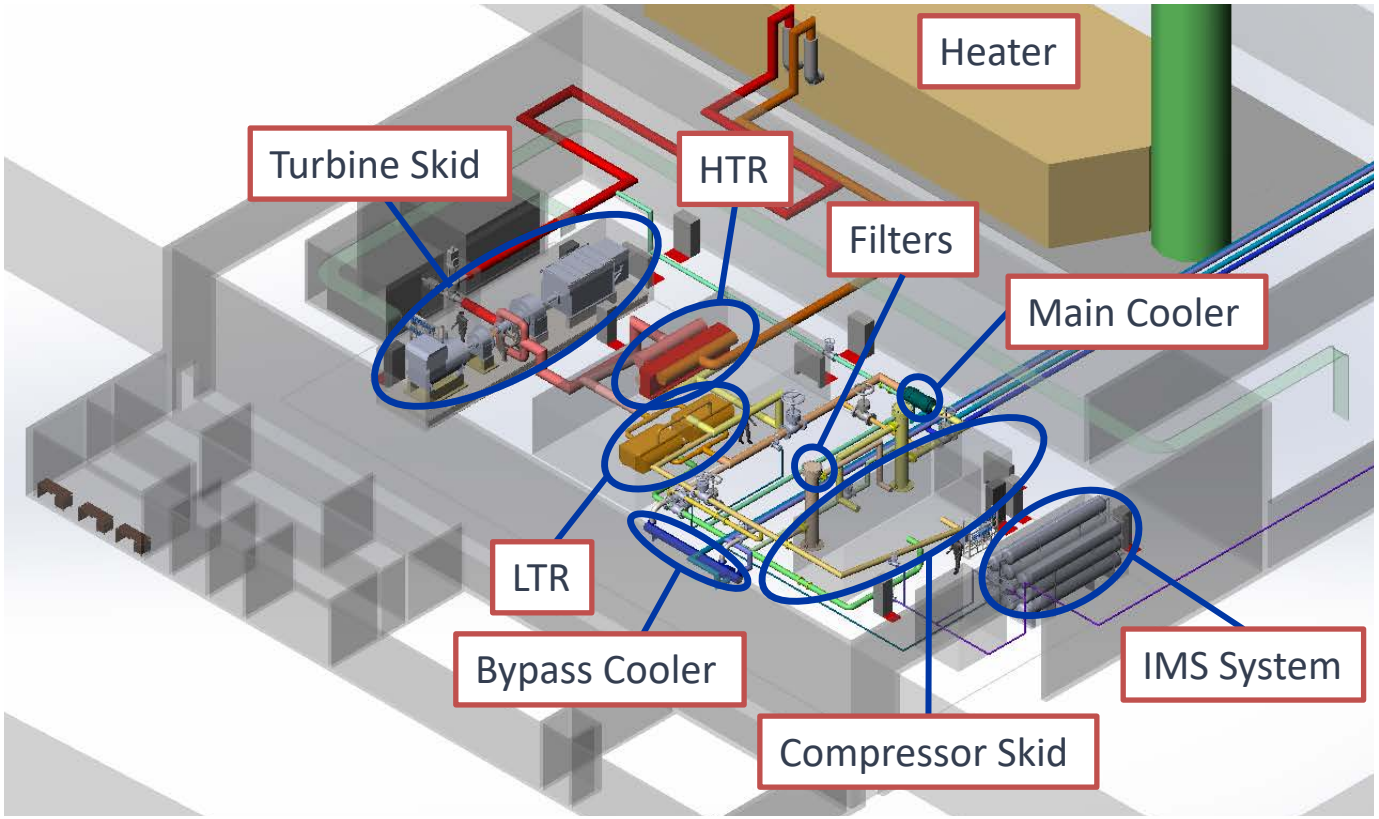
Reconfigurable facility to accommodate future testing



Pilot Site: SwRI in San Antonio, TX

STEP Test Facility

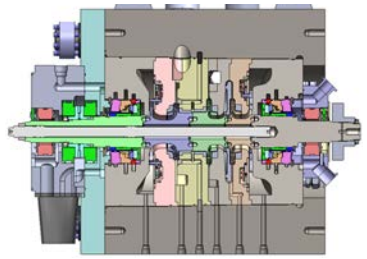
- Facility design
  - Provides sufficient flexibility to support future testing and demonstration activities
- Key facility features
  - Process hardware located in a controlled highbay
  - Oversized machinery foundations
  - Natural gas fired heat source
  - Provisions for auxiliary cooling capacity
  - 16 MWe distribution capacity, 10 MWe interconnect
- Ground Breaking October 15, 2018



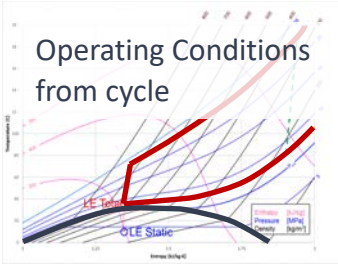
GE-Apollo High-Efficiency sCO2 Centrifugal Compressor Development (GE, SwRI for DOE EERE)

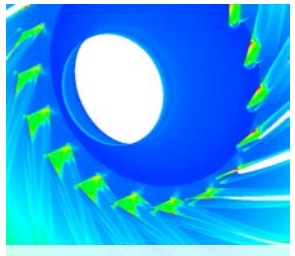
- Develop high-efficiency sCO2 compression system for operation near the critical point
  - Main Compressor Efficiency of 80% using a high efficiency centrifugal impeller
  - Variable IGV/OGV to accommodate fixed speed operation
  - Extended flow range to accommodate swings in ambient temperature
- Aerodynamic design provided by GE and implemented into a compressor design provided by SwRI
- Full scale testing at 10 MWe sCO2 cycle conditions to verify compressor mechanical and aerodynamic performance over a range of operating conditions

Compressor Mechanical Design

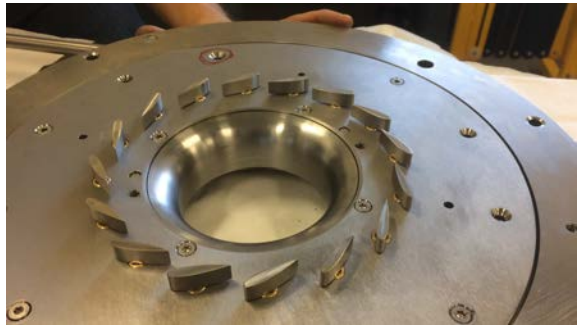


Compressor Aerodynamic Design





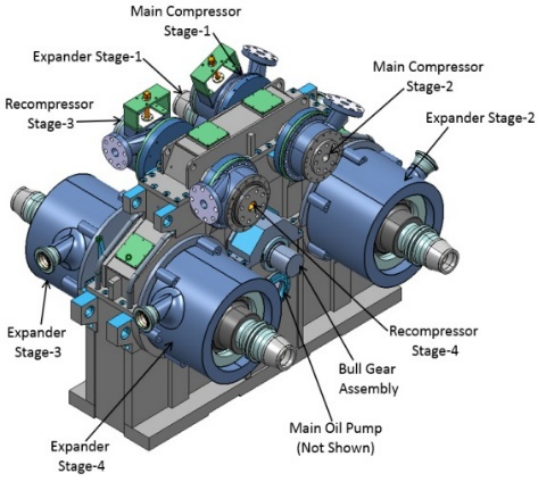
Flowpath Simulation



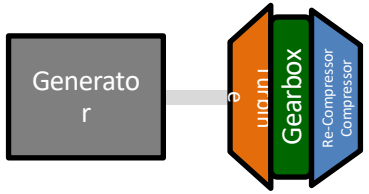
Variable IGV Design

Apollo: Ultra High Efficiency Integrally-Geared sCO2 Compander (SwRI, Hanwha for DOE EERE)

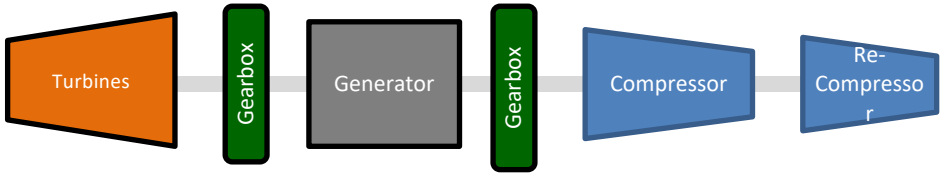
- Design a sCO2 integrally geared compander (IGC)
  - Combining compression and expansion stages into a single integrally geared housing connected to a low speed motor/generator.
- Benefits:
  - Reduced footprint
  - Potential cost reduction up to 35%
  - Utilizes a low speed commercially available driver/generator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



Typical IGC Package

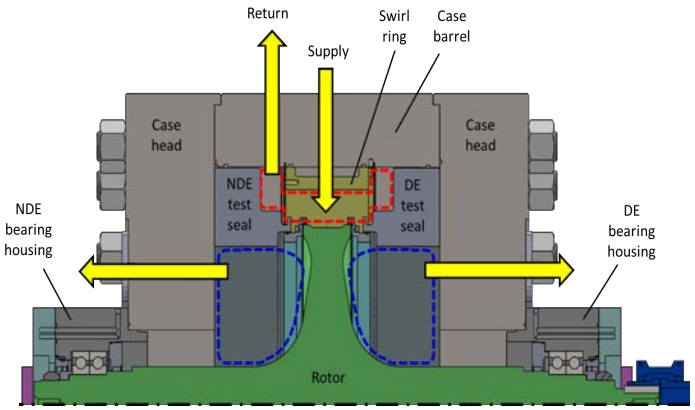


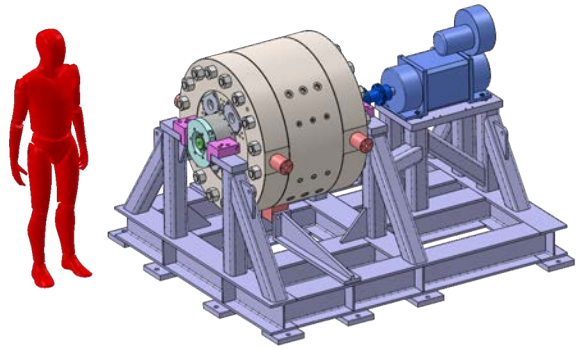
Conventional Turbomachinery Train



Testing of Shaft End Seals for Utility Scale sCO2 Turbines (GE, SwRI for DOE NETL)

- Seals for utility scale (450 MWe) sCO2 turbines are not commercially available
  - 24 in. end seals at 75 bar
- Film-riding face seals increase cycle efficiency by 0.6-0.8 points
- GE is developing large diameter face seal technology
- SwRI developing rig to test full-scale seal prototype with sCO2
- Leverages existing test hardware developed for EERE SunShot





sCO_2 Program Status

- Sunshot Turbine – Complete
  - Achieved design temperature, speed, and pressure
  - Obtained valuable performance, design and control system data for future development
- Apollo Compressor – Middle of Testing
  - Achieved design speed and pressure. Compressor CO_2 near the dome
  - Currently troubleshooting mechanical issues and will continue testing in 2020
- Apollo Compander - Assembly
  - All major components have been delivered
  - Will be testing compressor followed by full power loop
- Utility Scale Seals Test Rig – Middle of Testing
  - Initial mechanical assembly and mechanical test complete
  - Will assembled with face seals and run full pressure performance tests
- STEP Pilot Scale Plant – Construction and Procurement
  - Design complete. Building is being constructed
  - Testing will begin in late 2020
- Oxy Combustion – Beginning
  - Received funding for one combustor test
  - Currently have proposals for more to develop oxy combustion technologies and further advance turbine development

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