PEREGRINE TURBINE TECHNOLOGIES

# sCO2 Symposium WHR Panel

## SCO2 Turbomachinery Developments

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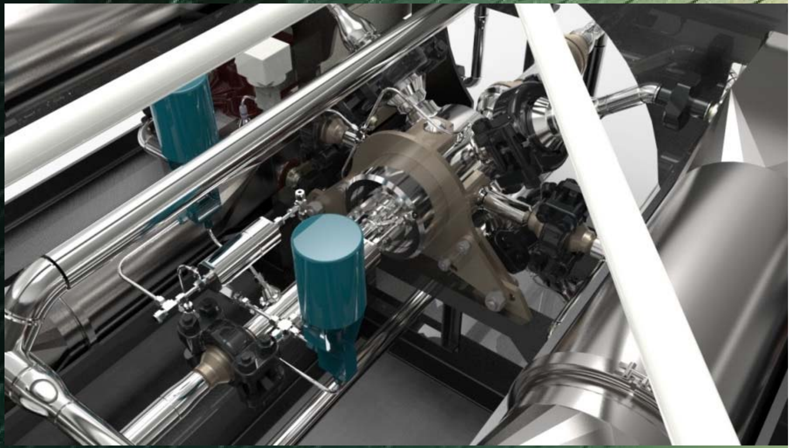
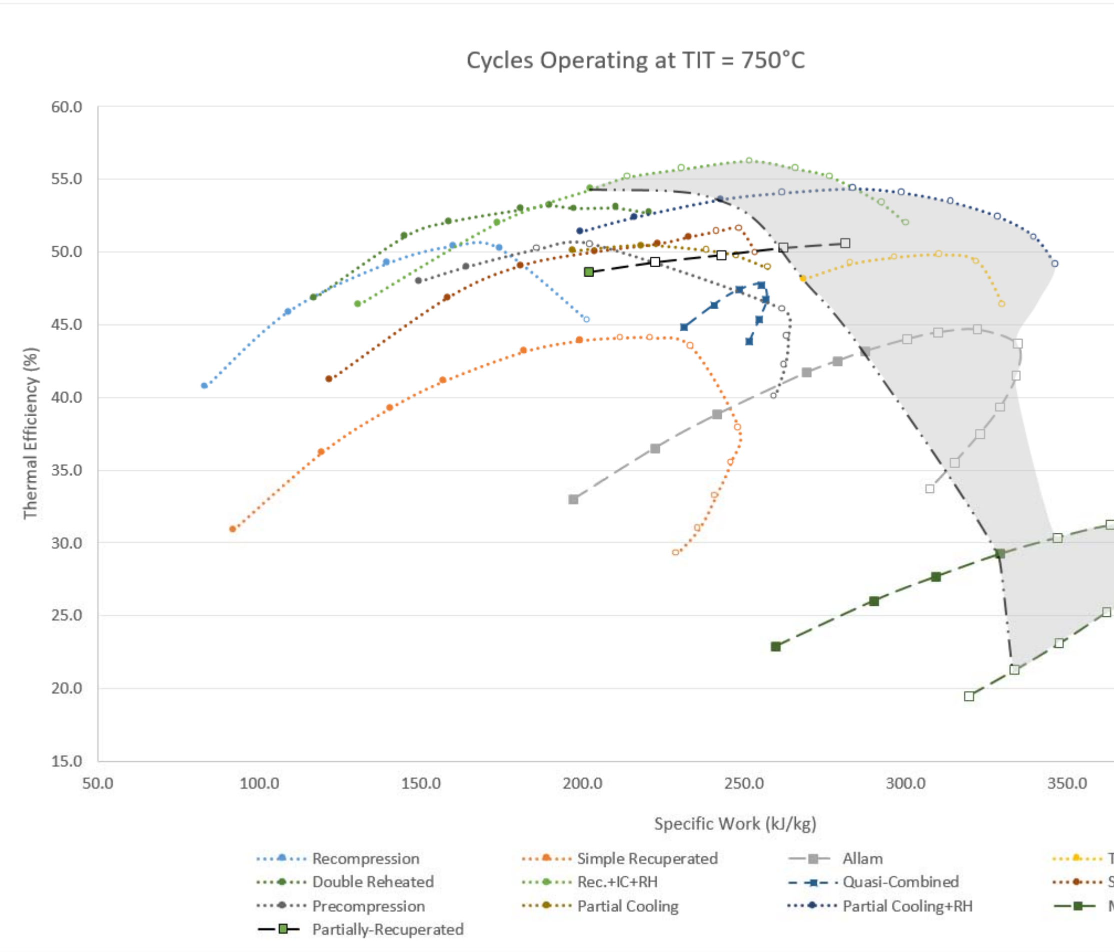


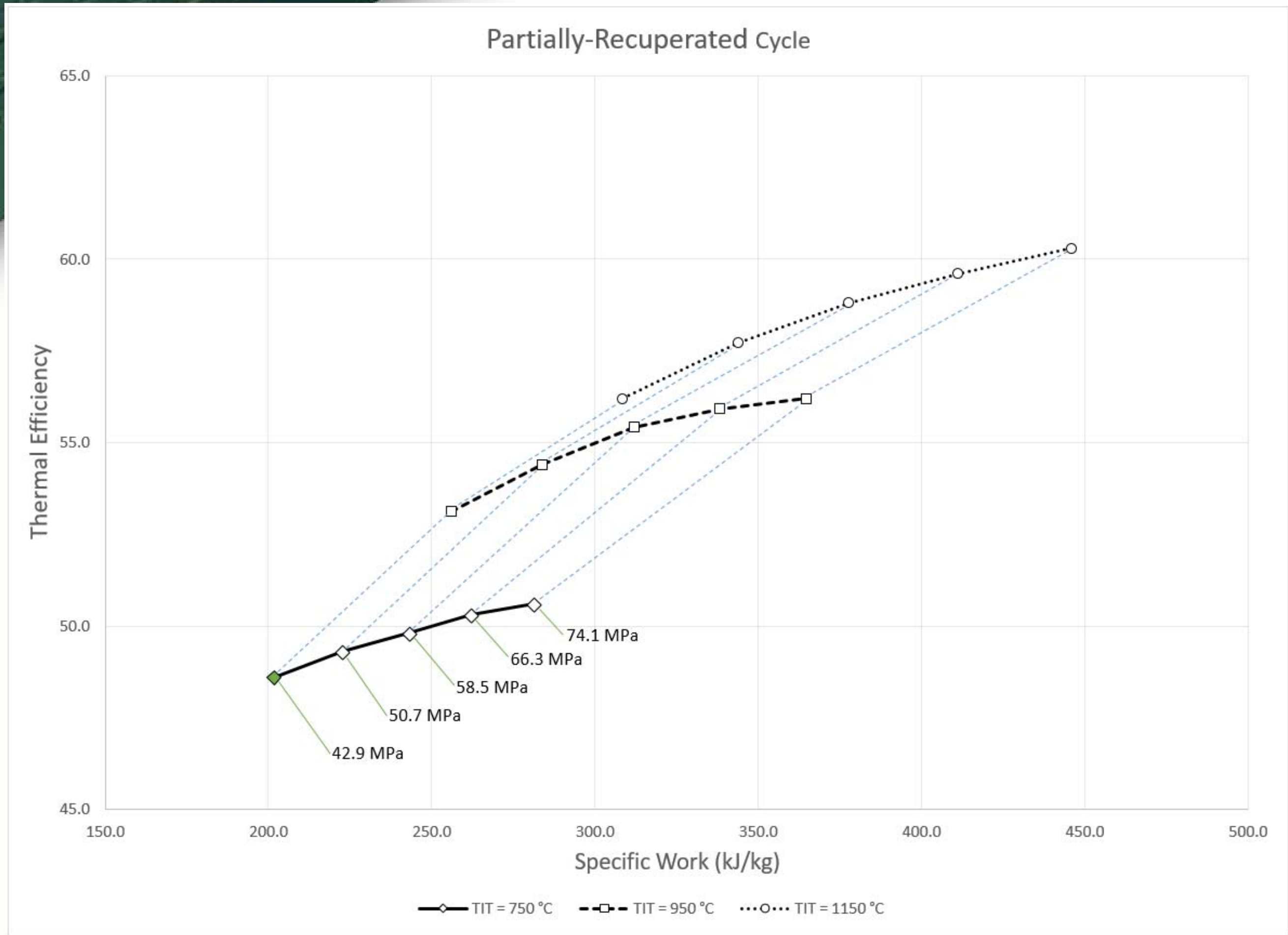
# What is the Right Target Pressure Ratio?




- Solid point markers indicate < 40 MPa peak pressure, except for Partially-Recuperated (P-R) cycle curve.
- P-R cycle operates at 42.9 MPa peak pressure.
- Square data markers indicate combustion-compatible cycles

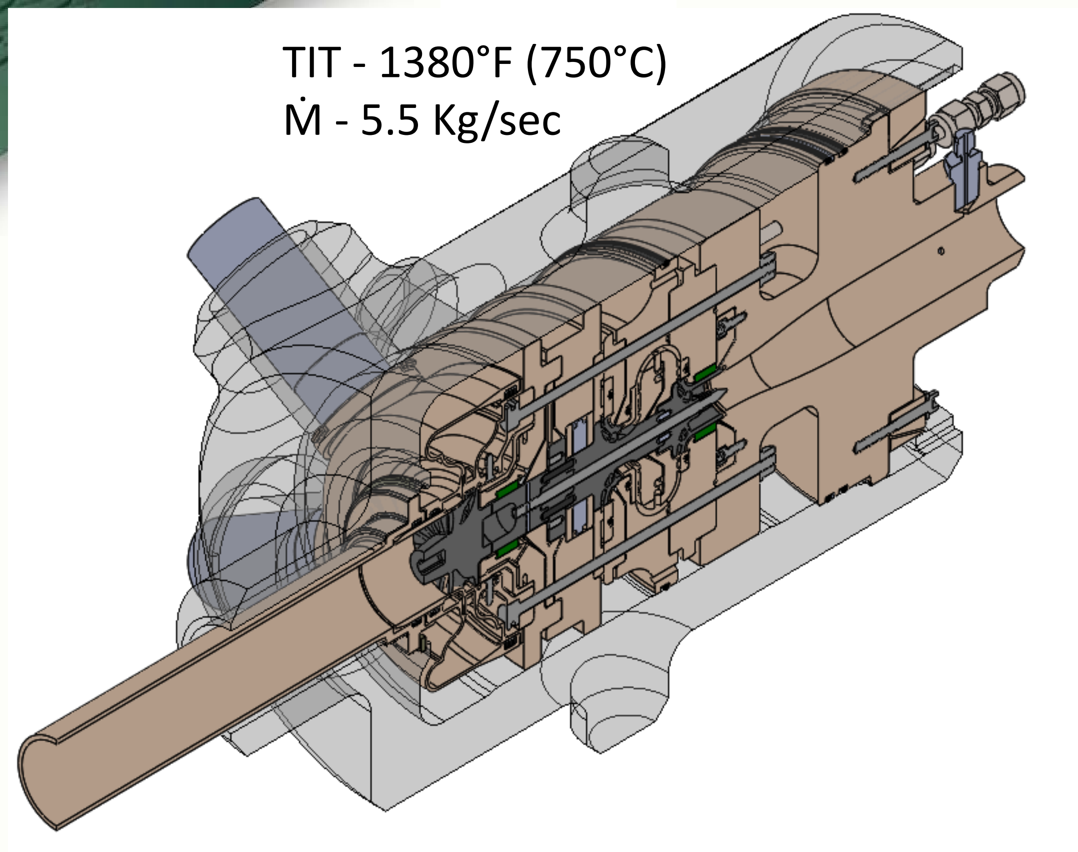
Work Presented at TurboExpo 2017 by Dr. David Sanchez, Univ. of Seville

# What is Possible with High Temp Primary Heat Exchanger?




Temperature Capability of Primary Heat Exchangers is Limiting Rather Than That of the Turbine Wheel

# Peregrine Turbine
# 1.0 MW Core




P3 - 6220 psi (42.9 MPa)

T3 - 196°F

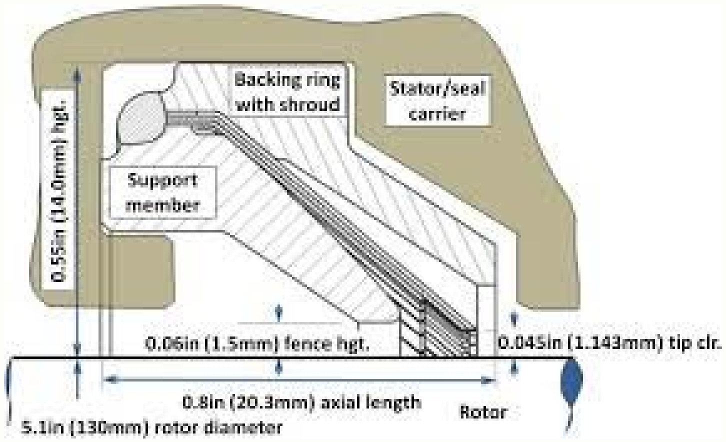
PR - 5.5

Ng ~ 118,350 RPM

Design Features

- 2 Stg Radial Compressor
- Radial Inflow Turbine
- Gas Foil Radial Bearings
- Gas Static Thrust Bearing
- Pressure Activated Leaf Seals
- 4 Radial Turbine Inlets
- 2 Radial Compressor Outlets

## Pressure Activated Leaf Seals (PALS) For Secondary Flow




The Problem

- Conventional Labyrinth Seals Result in Cross-Coupled Stiffness and Potential Rotordynamic Instability in sCO2.
- High Delta Pressures Result in Large Flows for Conventional Seals and Large Performance Charges to the Cycle.
- Soft Radial Bearings such as Gas Foils Can Result in Large Seal Wear-In Clearances Caused by Transiting First Rocking and Translation Modes during Start and Shutdown

The Solution

- Seals that Run Open at Low Speeds and Close Down to Rotor Orbit at Design Speed

Currently at TRL5

# Dry Gas Seals (DGS) for Power Turbine Shaft

Currently at TRL8

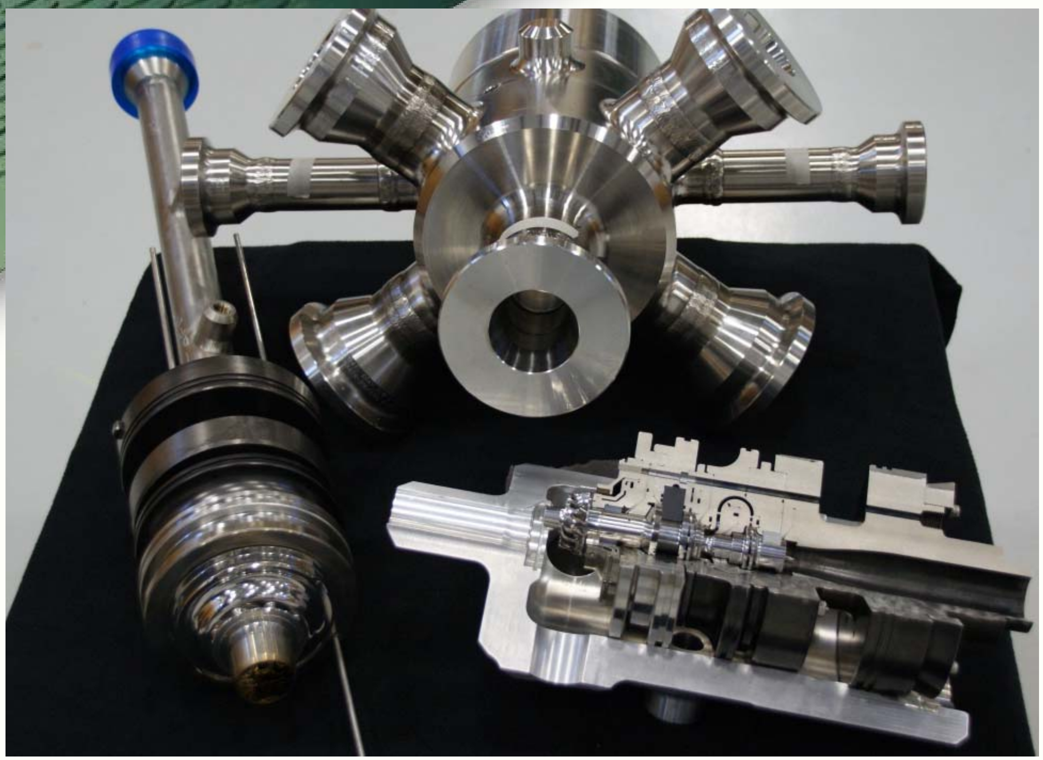
The Problem

- Large Pressure Delta to Ambient Combined with High Shaft Speeds
- Dense, Low-Viscosity $sCO_2$ Hard to Seal
- Cycle Efficiency and Economics are Sensitive to Flow Leakage at Shafts

The Solution

- DGS or Process Seals are Known for Very Low Leakage. Efforts by Major Manufacturers Crane and Flowserve to Optimize Designs for $sCO_2$ Applications

# Peregrine Turbine 1.0 MW Core

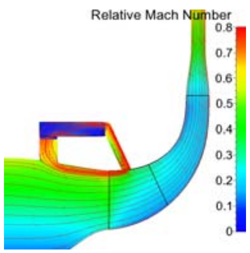


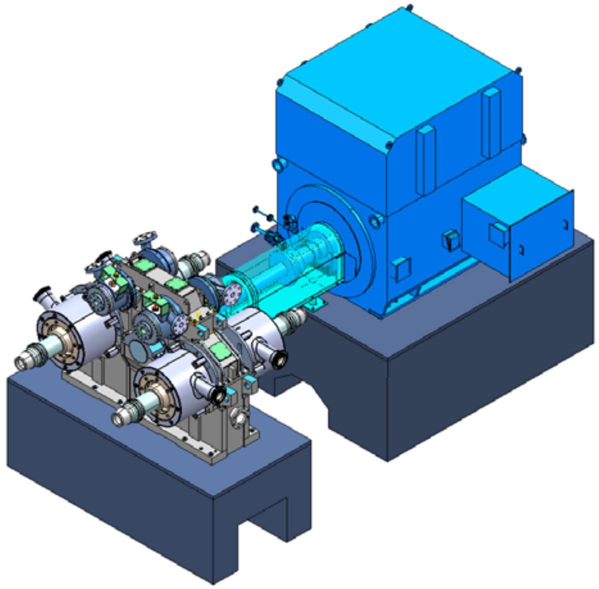
- Core Turbomachinery is Removable as a Cartridge
- Casing Stays with Piping Network
- Turbopump will be Tested in Sandia's Brayton Test Loop
- Pressure Ratio Set by B31.1 XXS Pipe Pressure Limits
- CDR Completed with AFRL Chief Turbine Engineer August 2017
- First Build Completed November 2017
- TRL6 to be Achieved Q2 2018 During Tests in the Sandia National Labs Test Loop.

Turbopump Design Partly Funded by AFRL and ONR

# PTT Engine Core Being Assembled into Sandia Test Loop

# DOE Funded Program to Develop Integrally Geared Compressor-Expander for Recompression Brayton Cycle



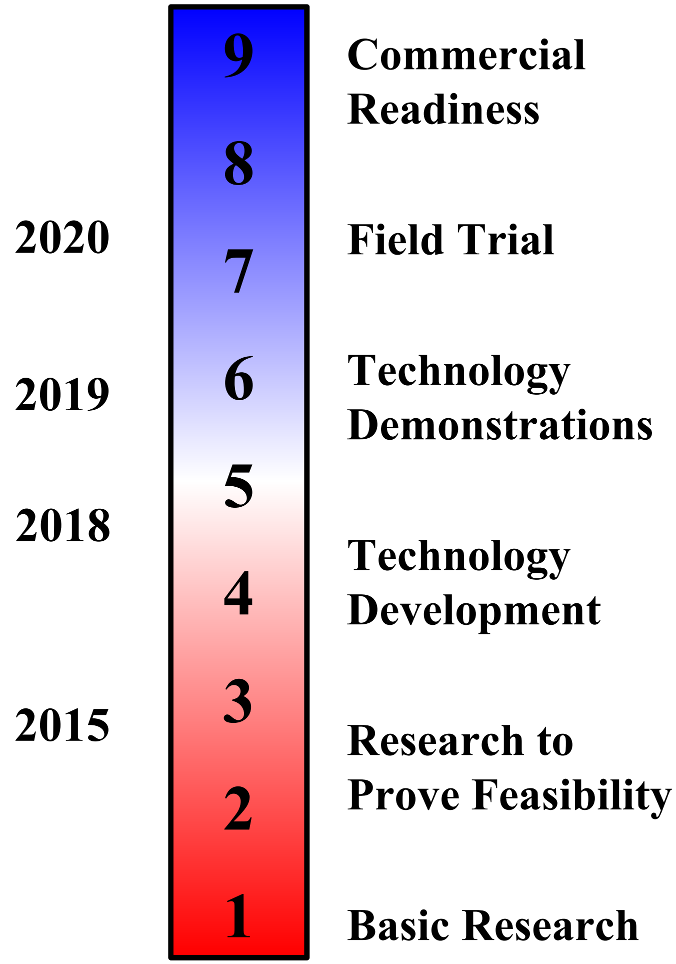



**10 MW$_e$ Cycle Using an IG Compressor-Expander Configuration:**

- TIT of 705°C
- 50% efficiency at design point
- wide-range compressor (50-70% range)
- Targets CAPEX and LCOE (900$/kWe, 6¢/kWe)

- Integrating advanced manufacturing, wide range compression into a challenging pressure-temperature

**Technology Readiness Level**

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# Conclusions:

- Pressure Ratios Above 5.5 Currently Achievable within B31.1 Piping Limits. System Topology is the Key
- TIT of 750°C Not a Difficult Objective for Turbomachinery
- Seal Designs Still in Need of Further Development/Testing
- Near Combined-Cycle-Level Efficiency Appears to be Achievable in Much Smaller Primary Cycle Systems with HX and Turbocompressor Development
- Determining Factor will be Development of Ceramic or Other High Temperature Primary Heat Exchangers