sCO2 Turbomachinery and Low-Leakage sCO2 End Seals

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Outline

- Overview – sCO_2 power cycles
- sCO_2 turbomachinery at GE
  - 10 MWe turbine
  - 450 MWe turbine
- End seals for sCO_2 turbines
- sCO_2 Seals test rig

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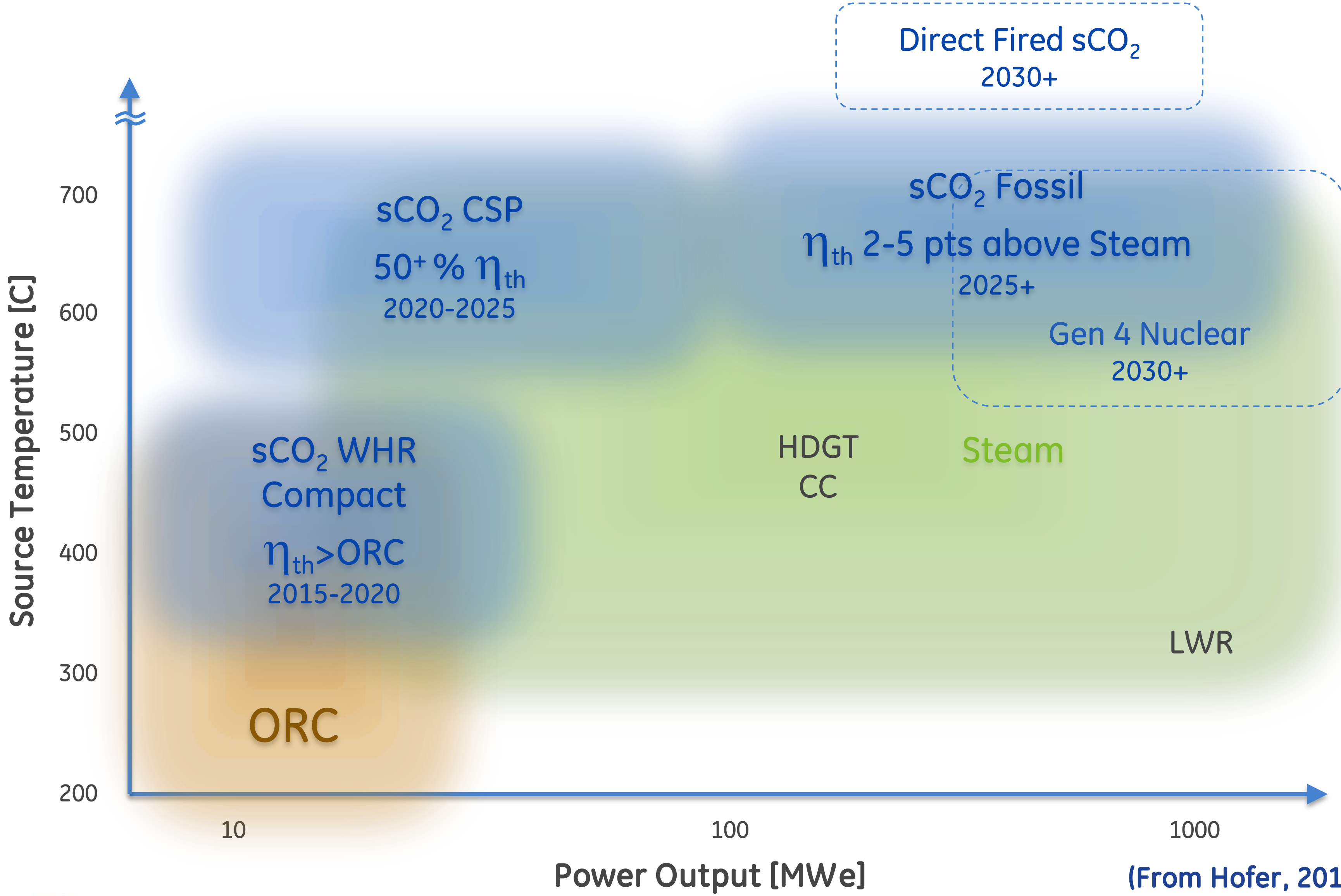
sCO2 Application Space



(From Hofer, 2014)

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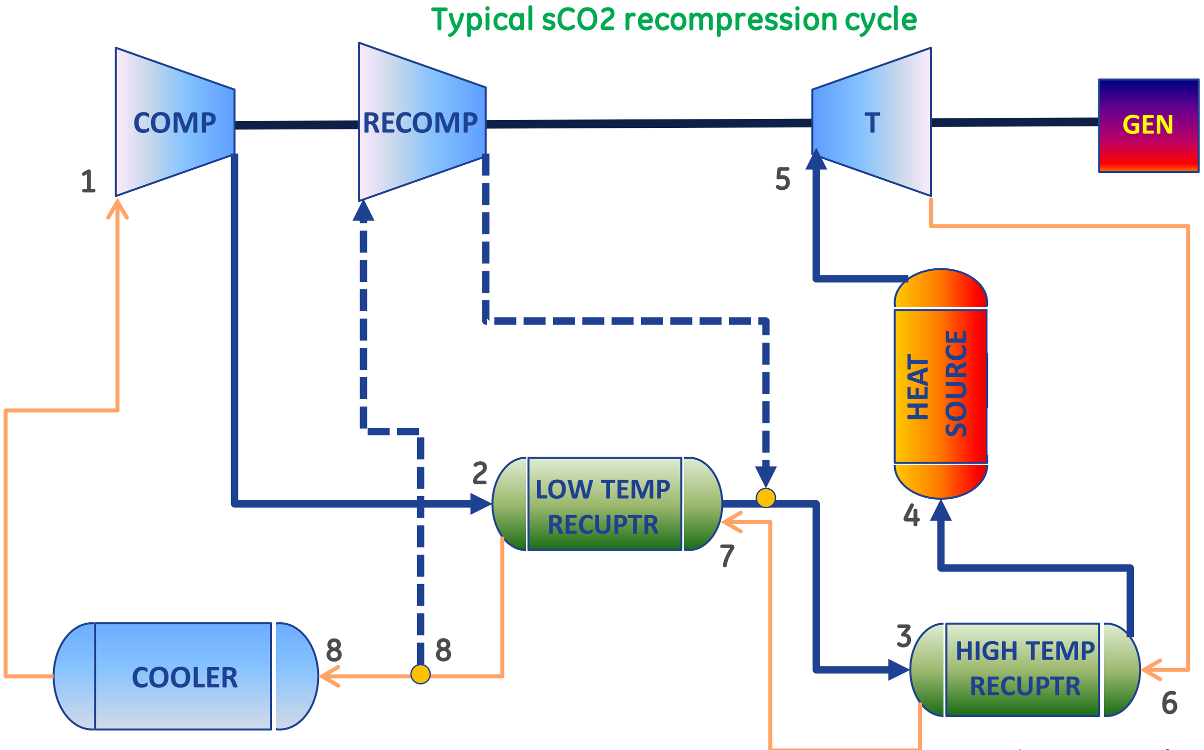
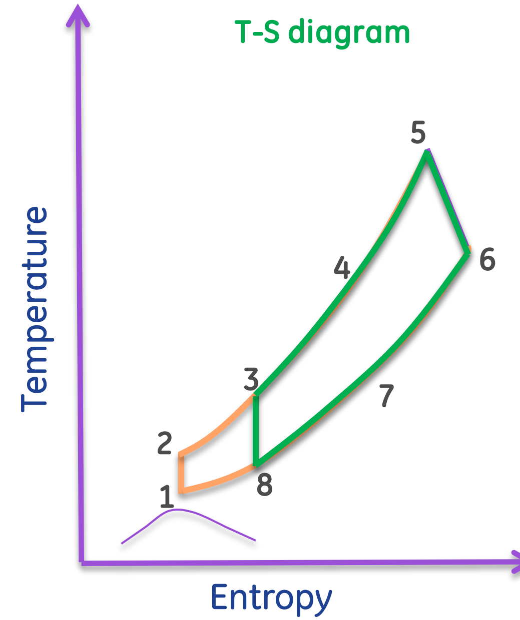
Recompression sCO2 Cycle





(From Kalra et al., 2014)

- Recompression sCO2 cycle for CSP and utility-scale applications
  - Recompression loop added for better recuperation
- Ongoing research in developing power plant components (turbines, compressors, recuperators)
- This presentation focuses on turbine maturation and turbine end seals for enabling higher cycle efficiencies

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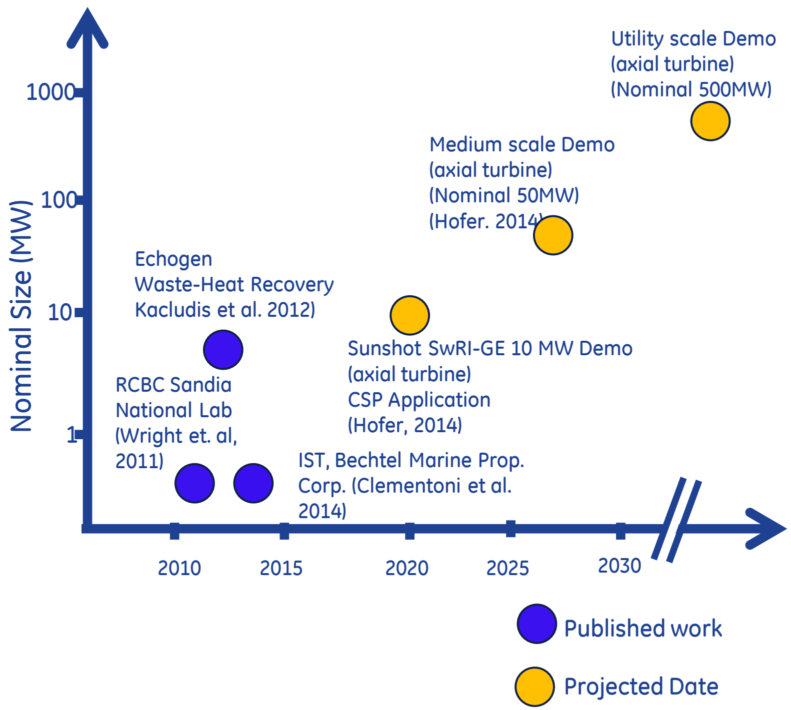
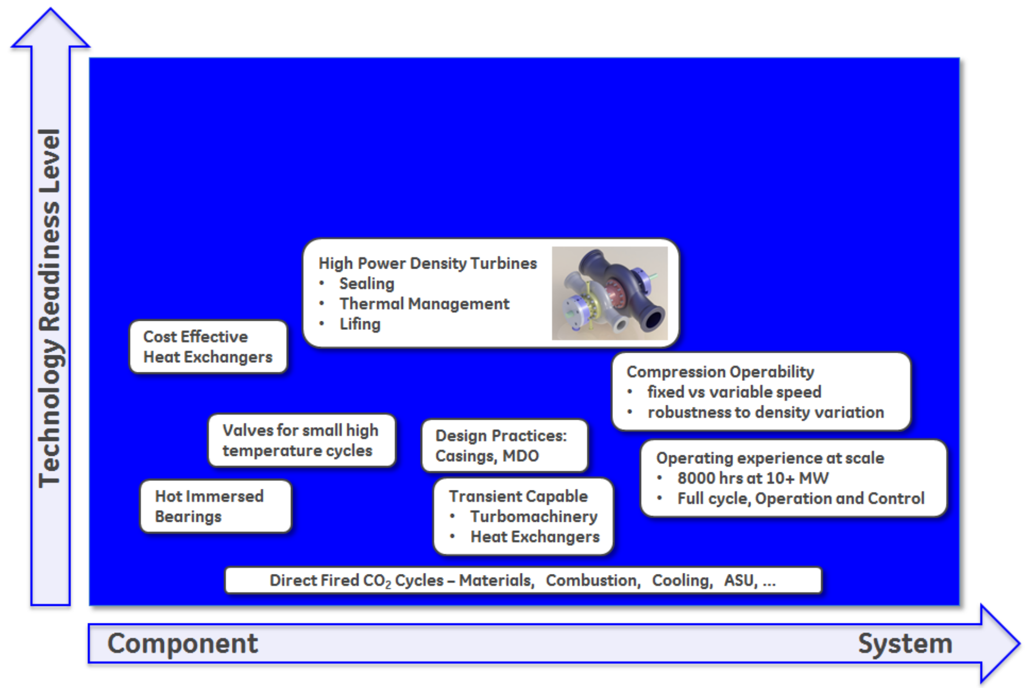
sCO2 power cycle roadmap & technology gaps

Timeline for sCO2 turbomachinery development



Technology gaps



(From Hofer, 2014)

Parallel development on components (Seals, bearings, valves) and materials to enable higher efficiencies

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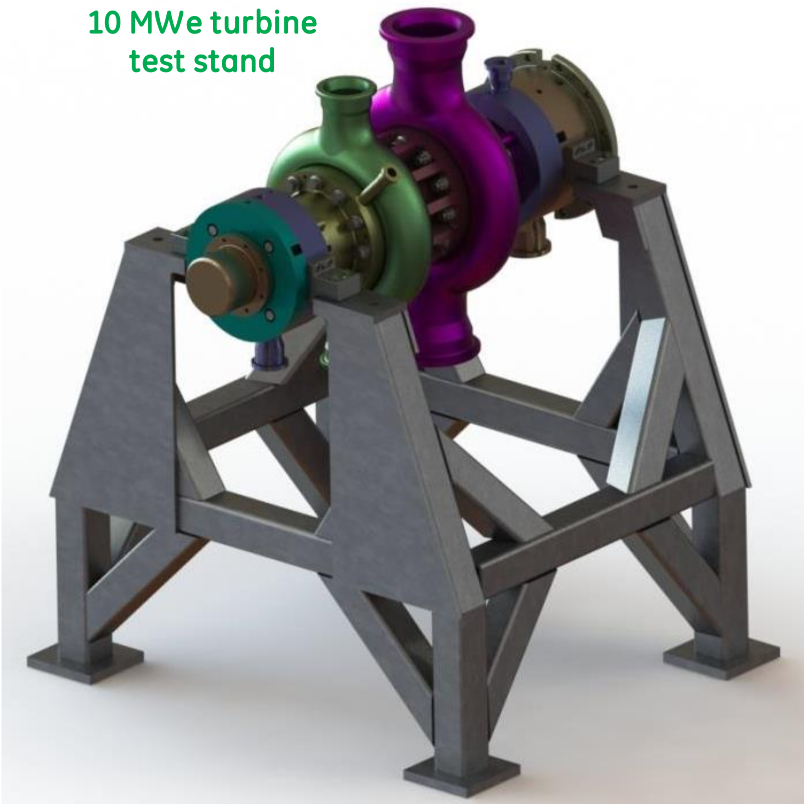
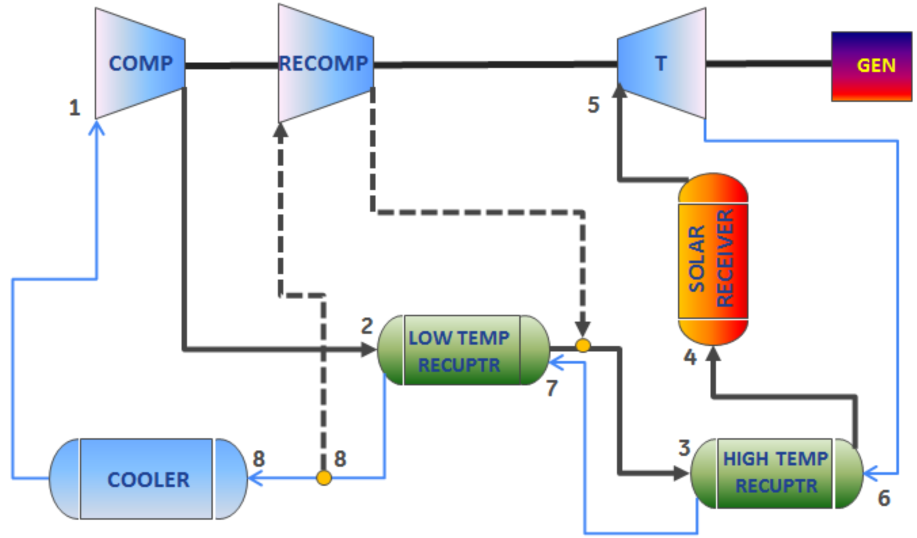
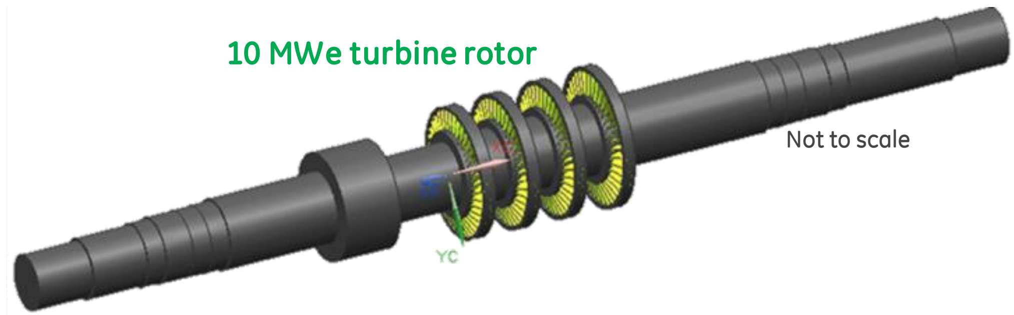
10 MWe SunShot turbine







- Very high power density turbine for CSP applications
- Key features
  - Supercritical CO2 aero design
  - Seals with thermal management
  - Bearings and rotordynamics

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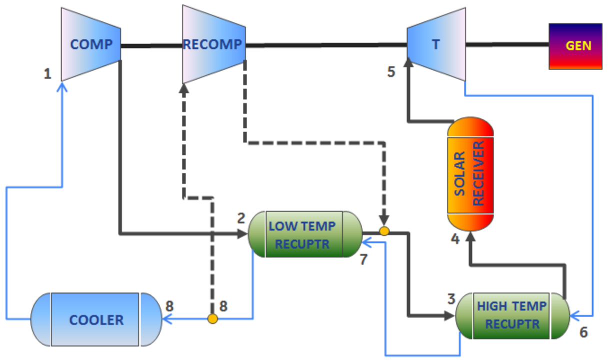
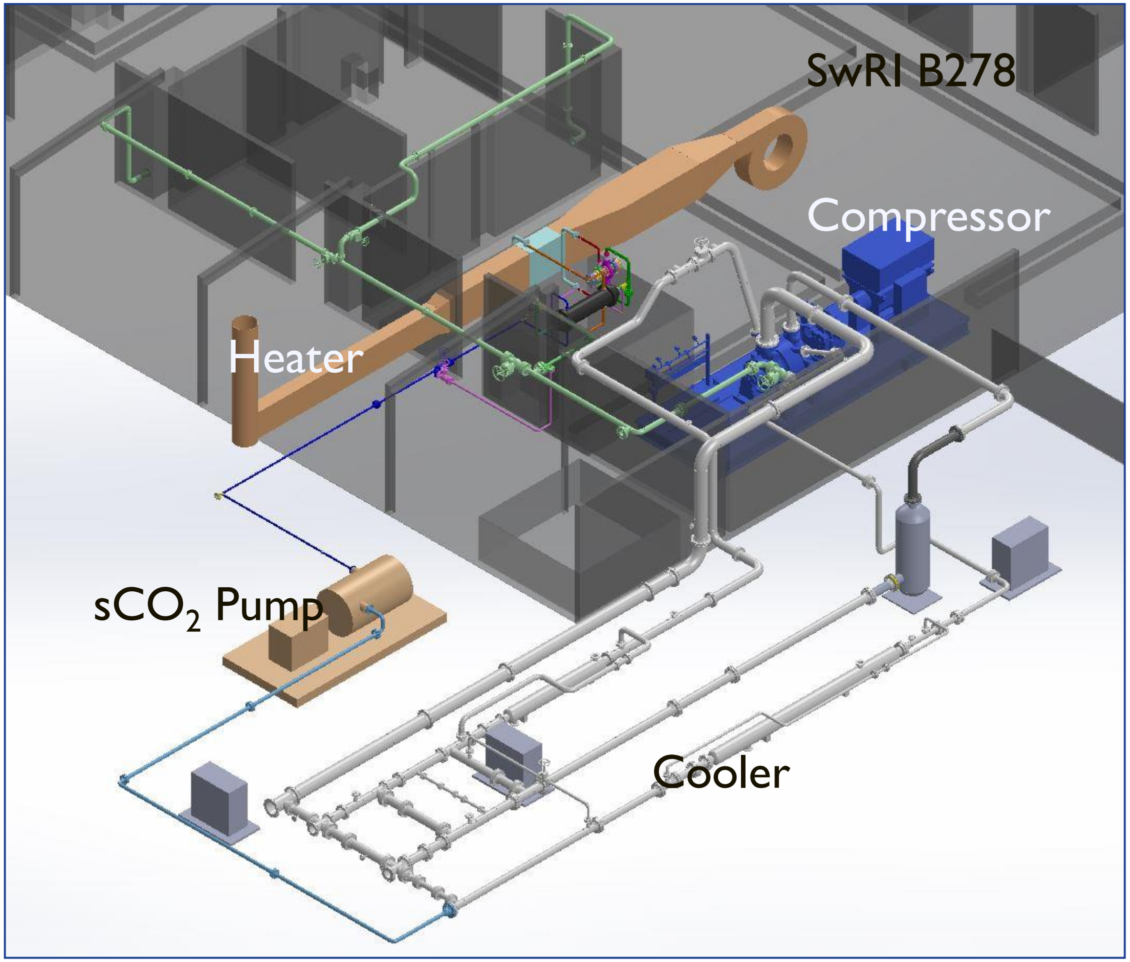
Test Loop –10 MWe turbine

Thermodynamic cycle



Picture of Southwest Research Test Loop

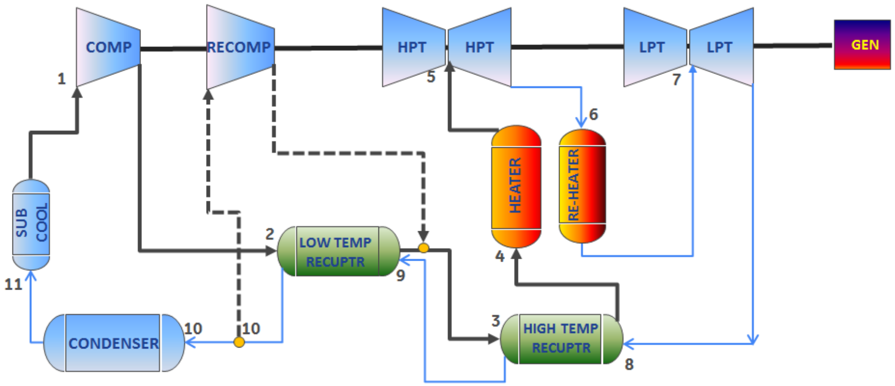
Representation of Southwest Research Test Loop



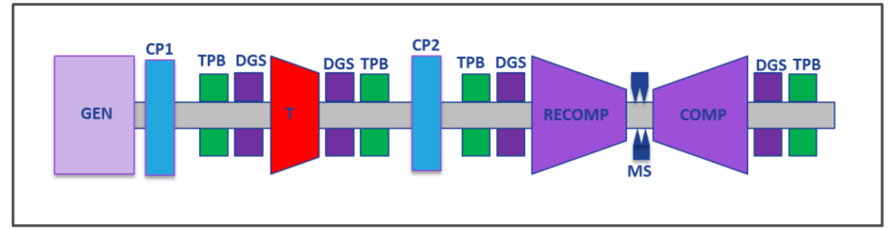
GE partnering with Southwest Research Institute in demonstrating the turbine

450 MWe – Layout Conceptual design & Cycle design

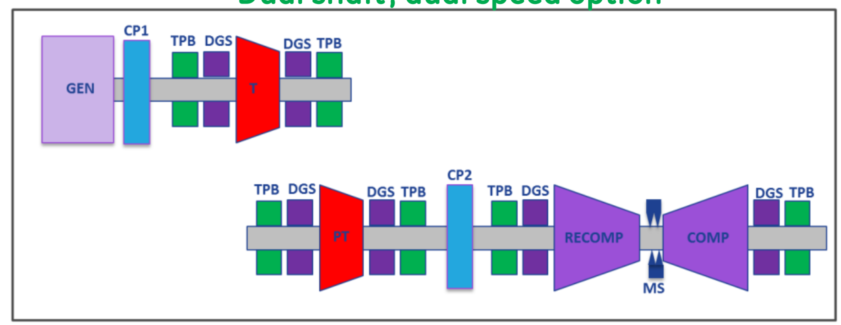
450 MWe Thermodynamic cycle



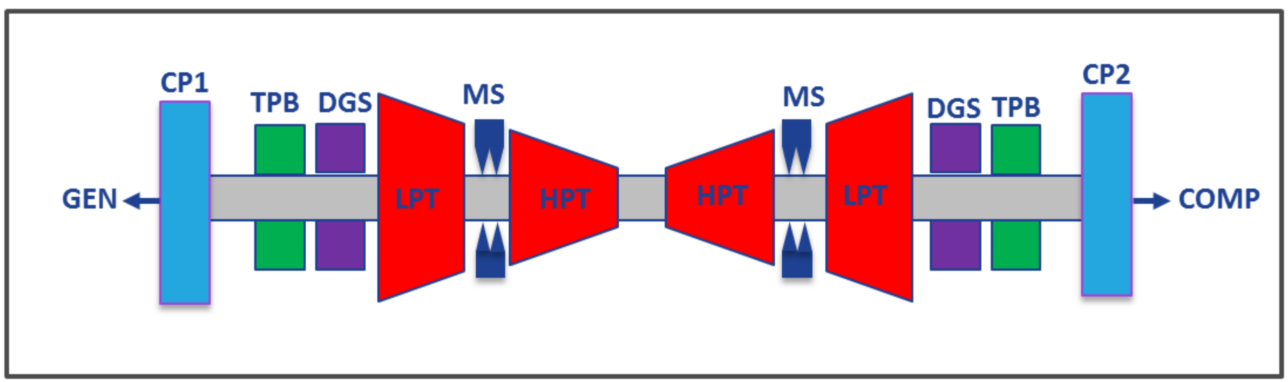
Single shaft, single speed option



Dual shaft, dual speed option



Final turbine layout – single shaft, single speed, dual flow, single casing



Reheat cycle with single-shaft, single speed layout and dual flow turbines to maximize efficiency

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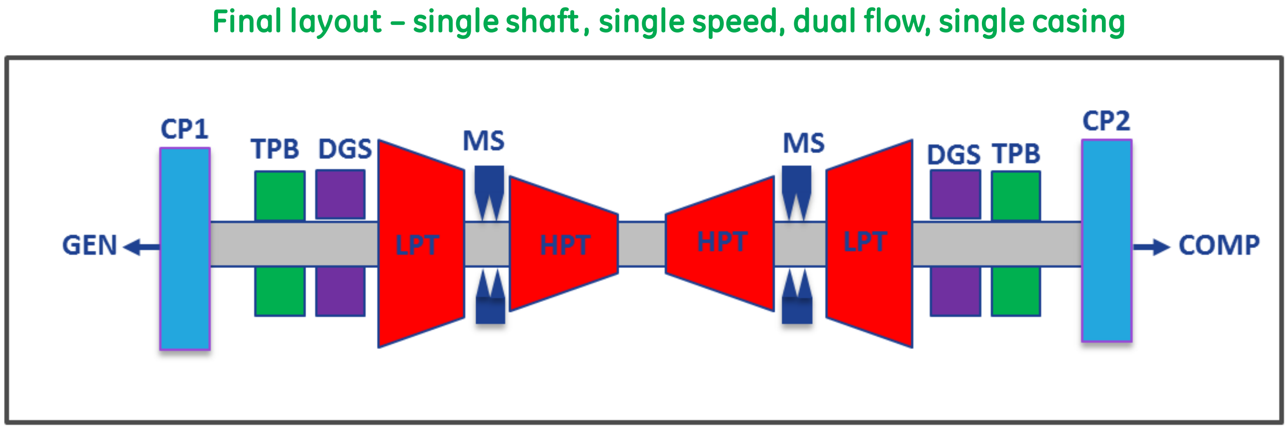
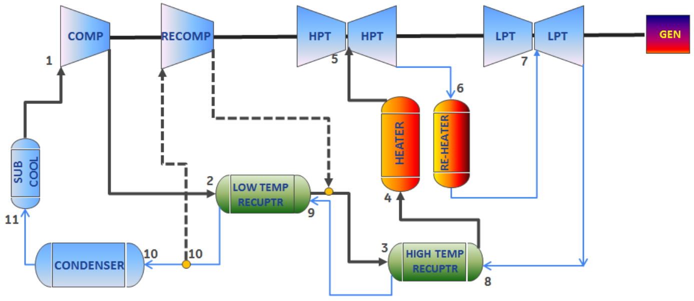
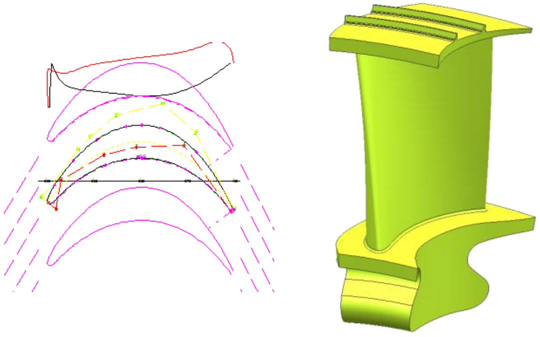
450 MWe Conceptual Design

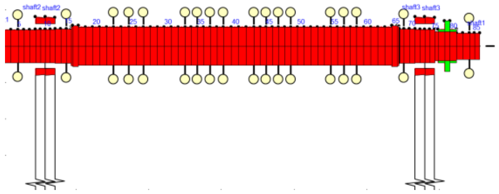




Systems



Aero & Mechanical



Rotordynamics

Turbine concept analyzed with thermodynamic cycle optimization, turbine aerodynamic and rotordynamic calculations

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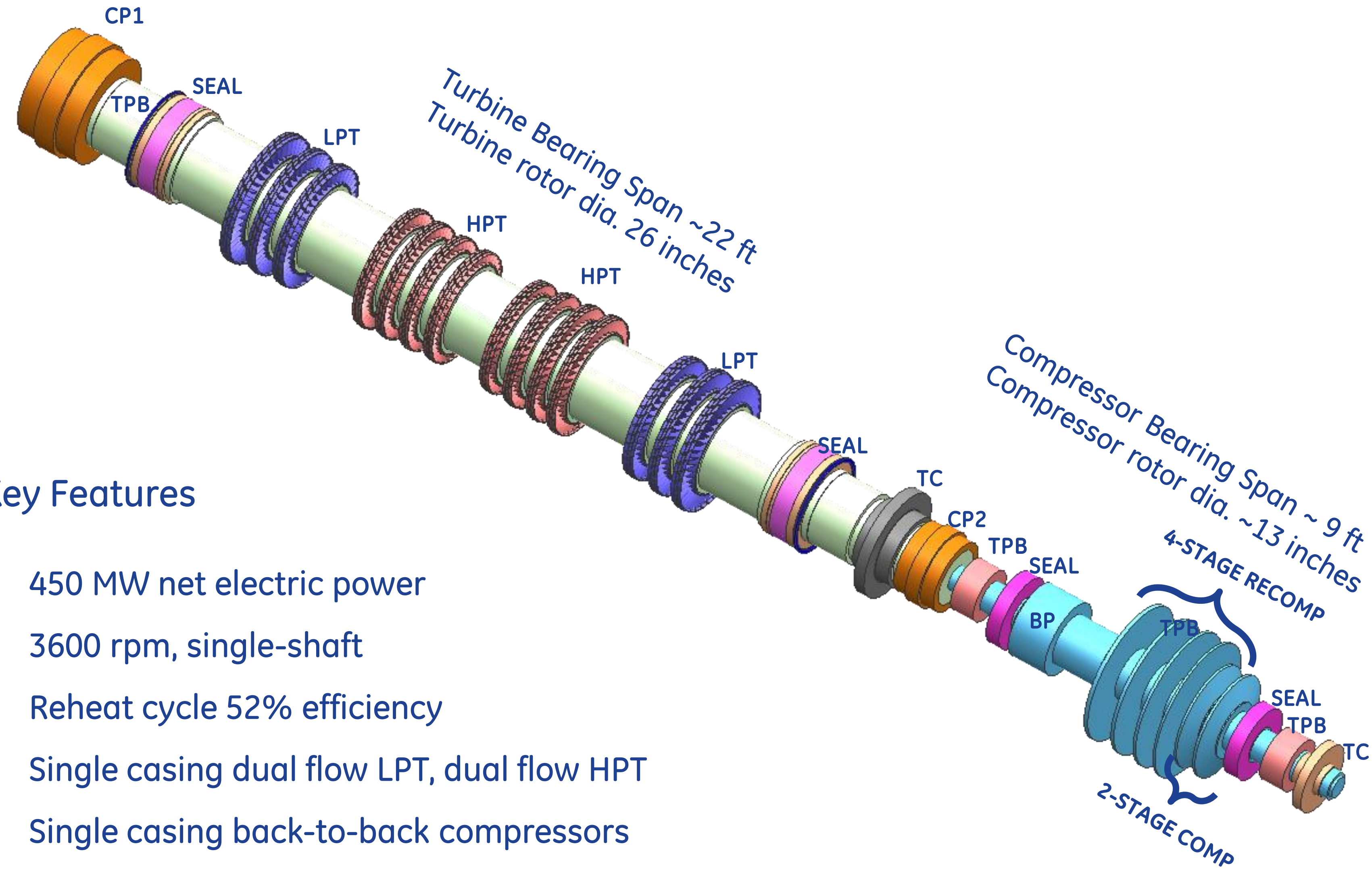
450 MWe turbine-compressor layout

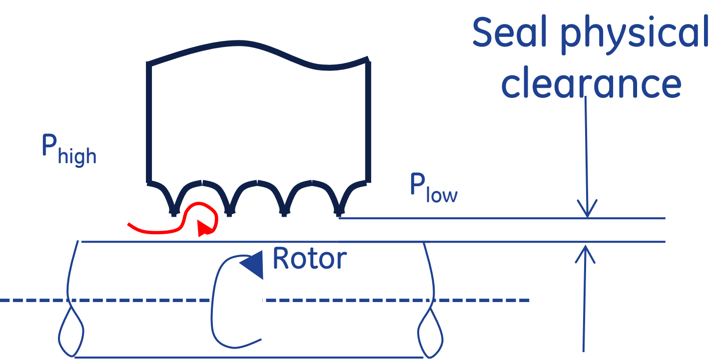


Key Features

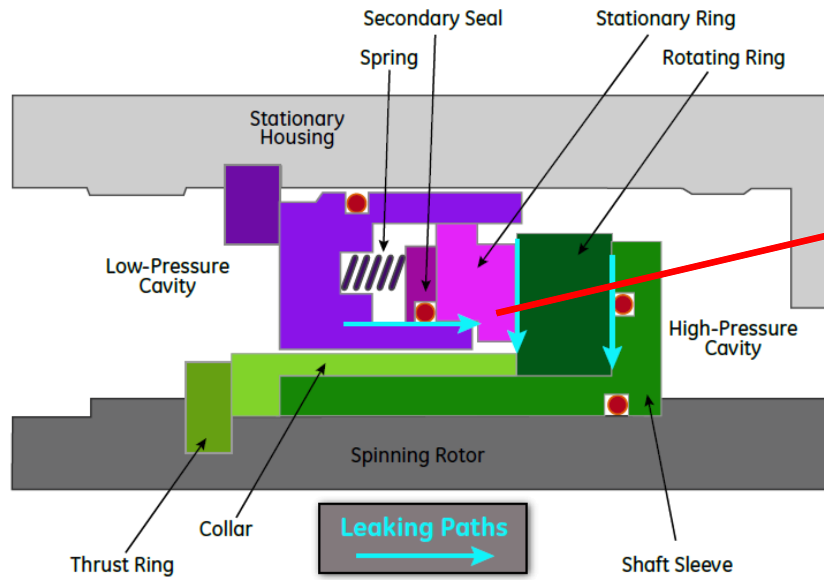
- 450 MW net electric power
- 3600 rpm, single-shaft
- Reheat cycle 52% efficiency
- Single casing dual flow LPT, dual flow HPT
- Single casing back-to-back compressors

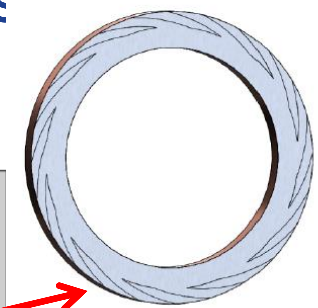
Motivation for using non-contact face seals (dry gas seals

Non-adaptive Laby seal



Adaptive Dry gas seal





Spiral groove geometry on rotor

- Laby seal:
  - Seal physical clearance varies during start-up, shut-down and cycle variations.
  - Teeth radius can be designed only for one operating condition leading to non-optimal gap and leakage loss at other operating points
- Non-contact Face seals
  - Stationary ring axially pushed towards the rotating ring. Spring biasing ensures a small physical gap under all operating conditions
  - Stationary and rotating rings have spiral grooves (or some other geometry) that generates lift-off pressure with speed & avoid contact

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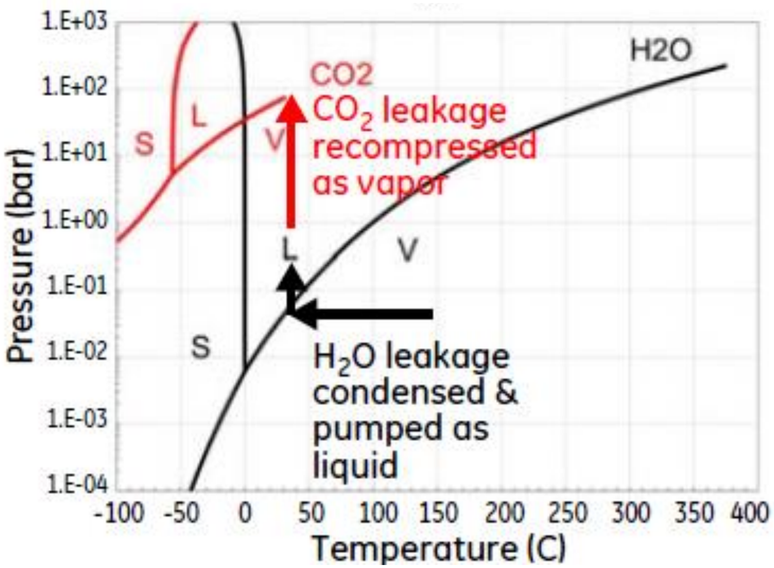
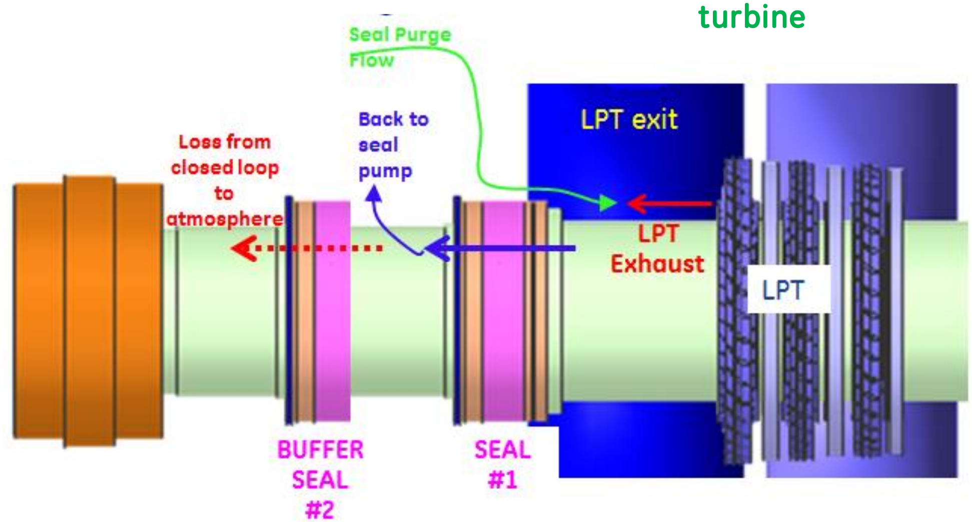
End seals for sCO2 turbines

Difference between Steam and CO2 leakage flow compression



End seal layout for a sCO2 turbine



- sCO2 cycles are unique
  - closed loop (unlike open loop gas turbines)
  - leaked CO2 needs to be recompressed as vapor (efficiency loss) unlike steam where the end leakage can be condensed to liquid and pumped back
- Seal CO_2 leakage has implications for cycle efficiency as well as CO_2 replenishment cost

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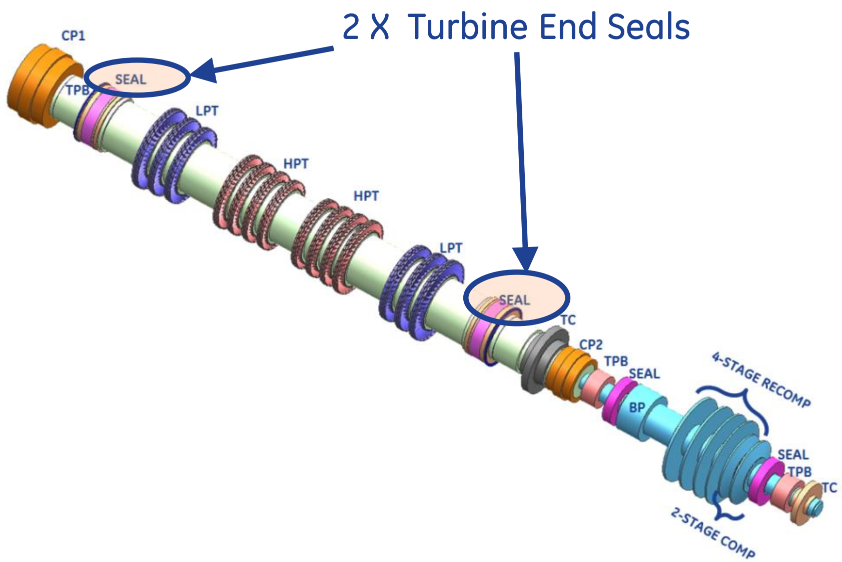
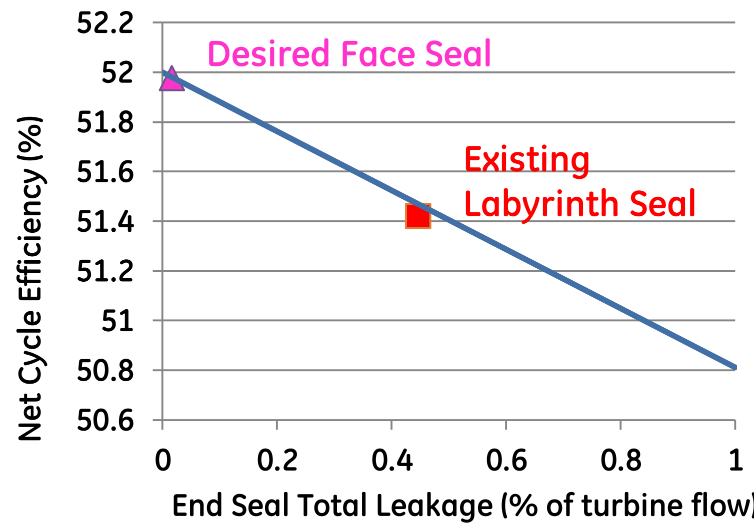
Turbine End Seal penalty analysis





- 2 x end seals on 450 MWe turbine are worth 0.55% cycle efficiency (1% loss of efficiency is worth $12/KWe)
- Alternate ways of regaining this efficiency (like increasing inlet temperature) are costly compared to developing seals
- Low-leakage seals are an effective method of keeping sCO2 cycles competitive over other power cycles

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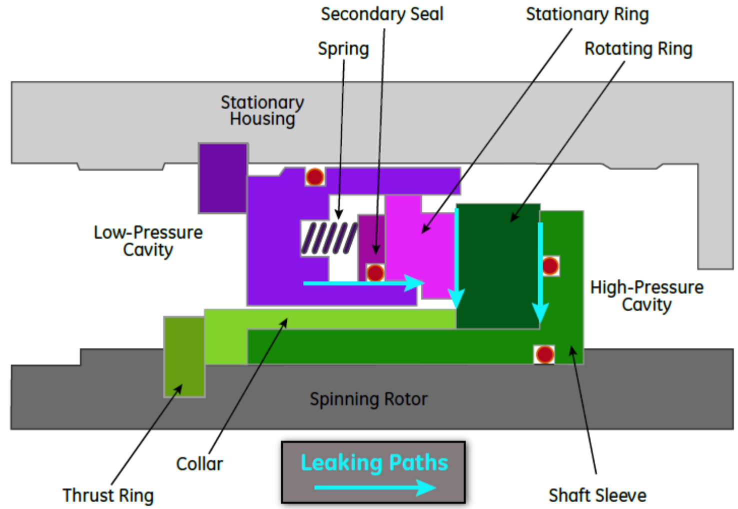
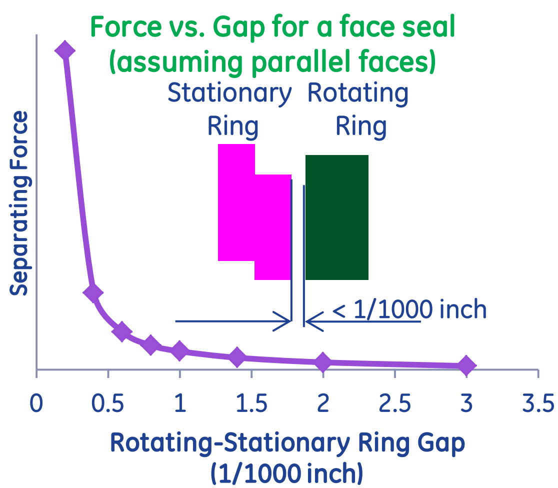
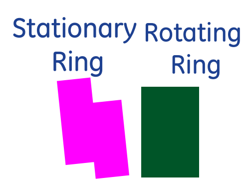
Seal Design Challenges

Seal operating conditions

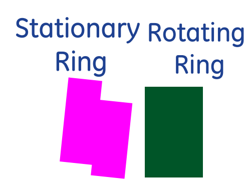
CTQ	Value
Diameter	24 inch
Pressure differential	> 1000 psi



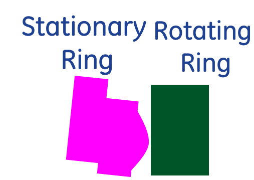




Deformed rings (rotation converging)



Deformed rings (rotation diverging)



Deformed rings (rotation & distortion)

- Maintaining parallelism between rotating & stationary rings is needed for successful seal operation
- Pressure & thermal loads, manufacturability at large diameter limit simple scaling of existing designs
- Innovative seal design features & detailed analysis needed to ensure parallelism

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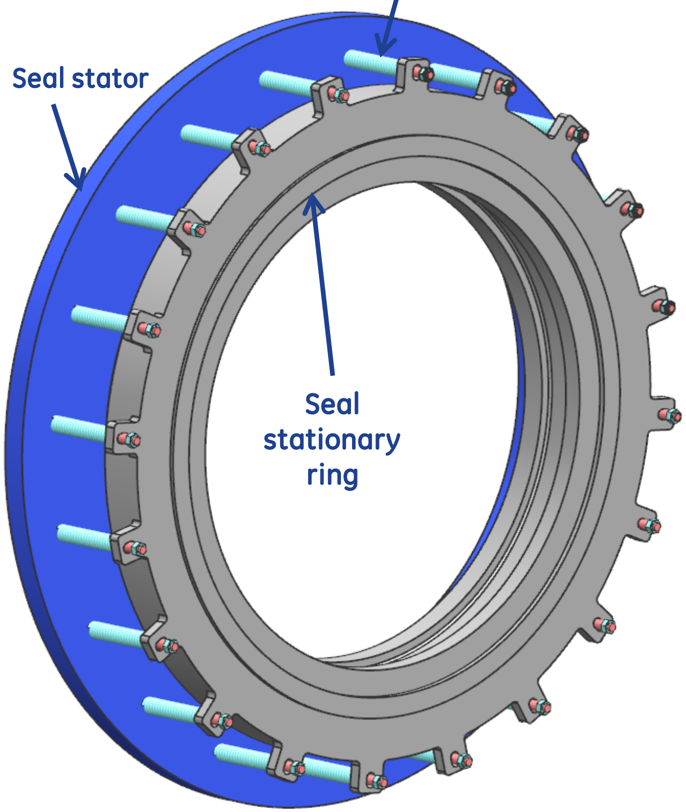
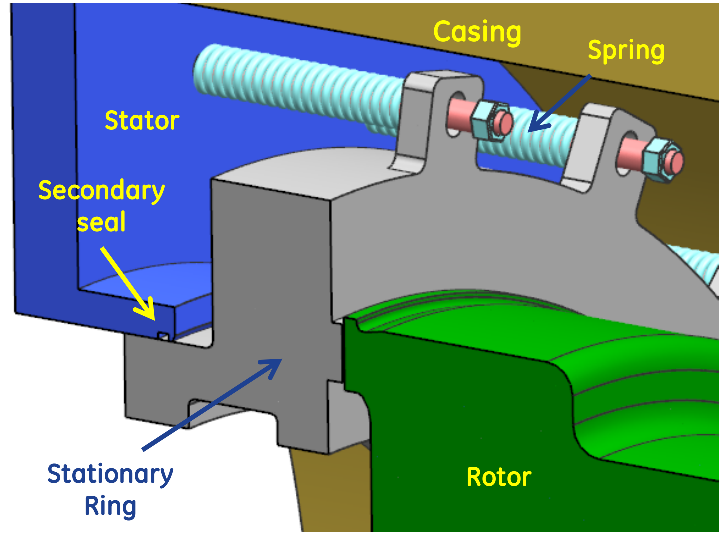
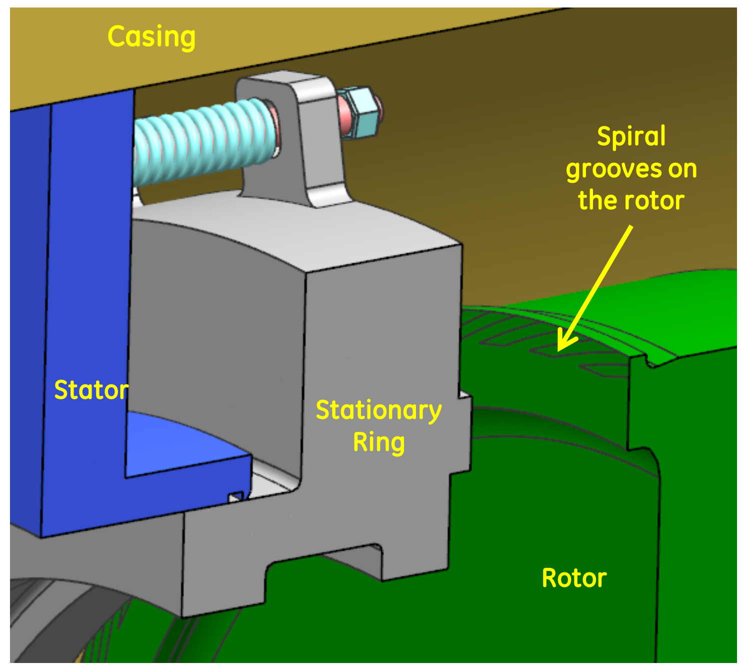
Seal Concept







- Springs & pressure bias the stationary ring towards the rotor
- Spiral grooves generate separating force
- Seal tracks rotor axial transients

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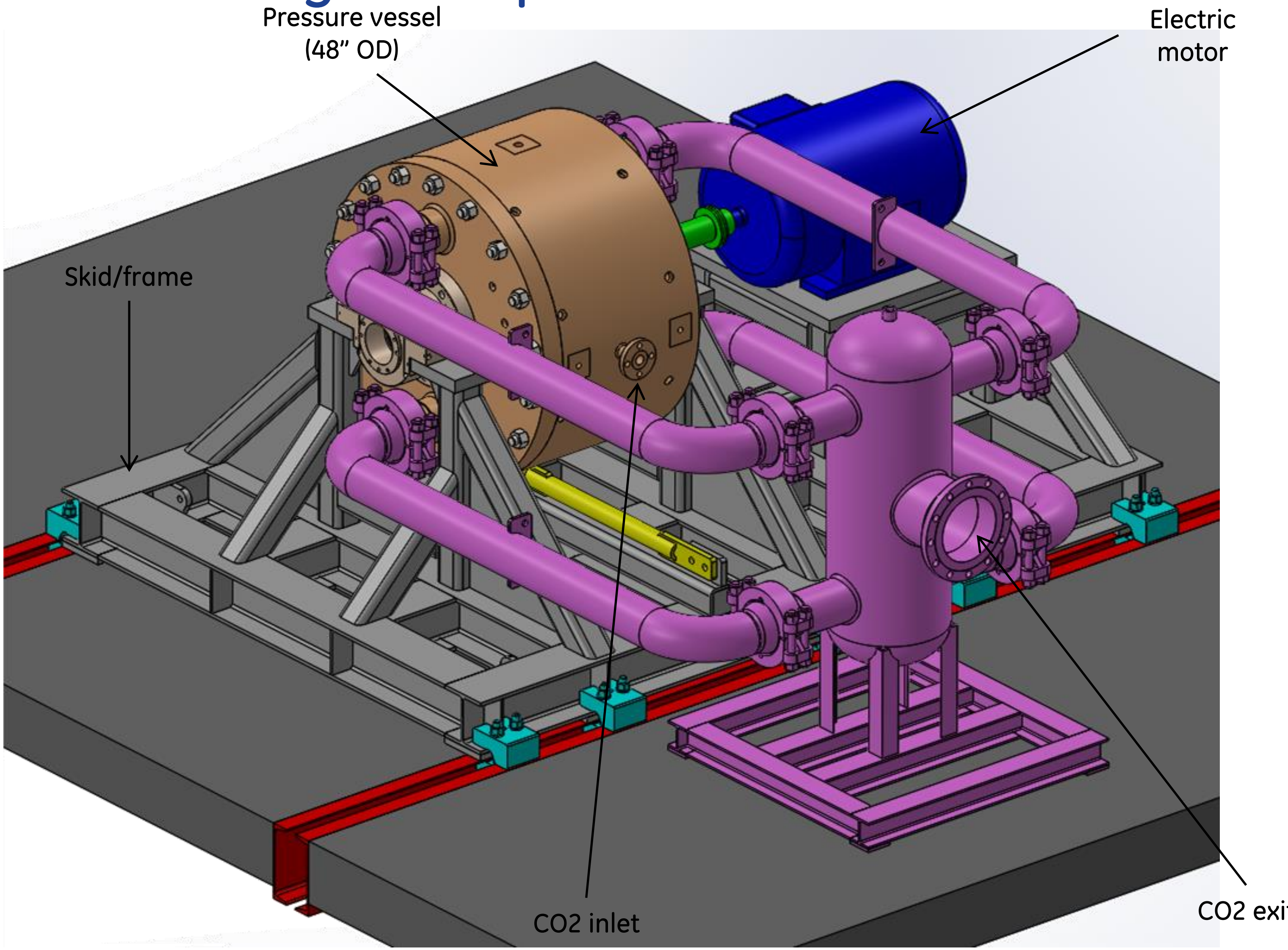
sCO2 Seals test rig concept

sCO2 Test Loop Concept



Seal test rig concept developed for high pressure, high temperatures and large diameter seals

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Summary

- sCO2 turbine development at GE
  - 10 MWe CSP application
  - 450 MWe utility-scale application

- Seal leakage can be significant penalty on cycle efficiency

- Seal concept and analysis, along with a Seals test rig concept

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3. Kacludis, A, et al, "Waste Heat to Power Applications Using a Supercritical CO2-Based Power Cycle," Power-Gen International, Orlando FL, 2012
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