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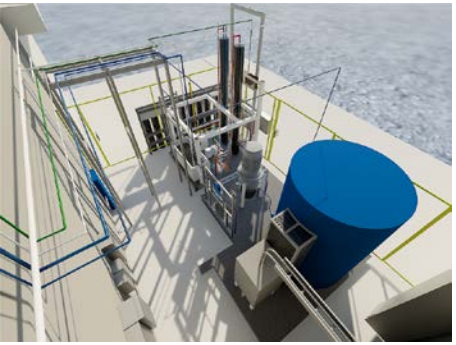

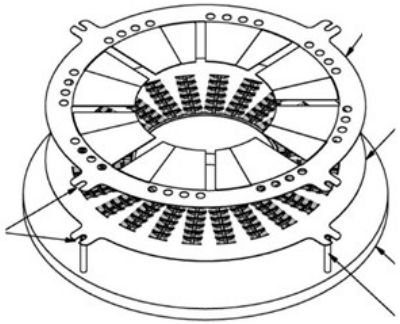

Experience with <1MW Supercritical Power Generation Technology Development

Darryn Fleming

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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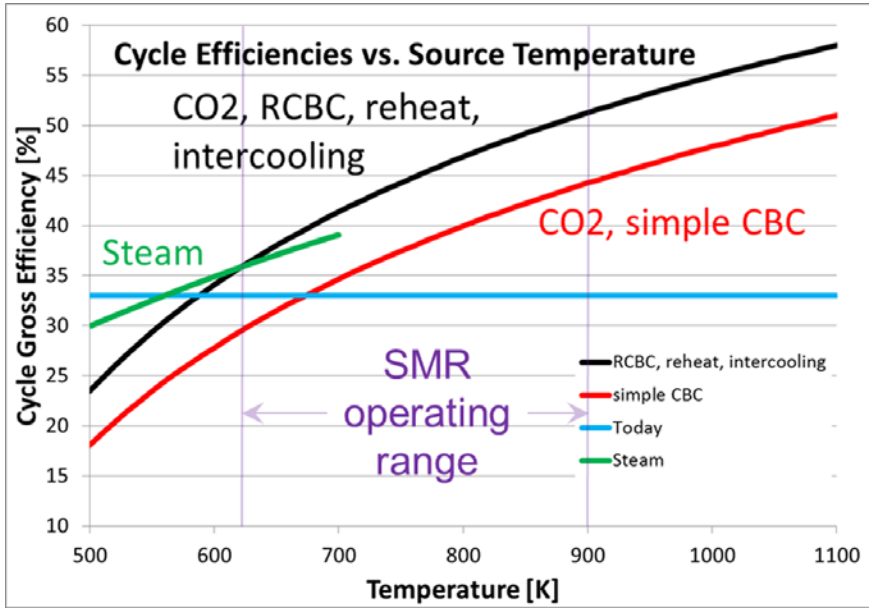
Outline

- Closed Brayton cycle history
- Sandia component development to advance TRL
- Ongoing challenges

Why the RCBC?

- Due to the great deal of internal heat recuperation, only a small amount of external heat input is needed, though at a high temperature.
- This cycle is ideal for mating with closed cycle heat sources, such as a nuclear reactor.
- The thermal-to-electric power conversion efficiency improves markedly with temperature, and surpasses steam at relatively low temperatures
- The single most impactful control variable in sCO_2 RCBC cycle performance is TIT
  - System pressure and pressure ratio
  - System mass loading
  - Compressor inlet temperature
  - Component efficiencies
  - TIT



This now becomes a significant materials challenge

RCBC system component evaluation

- Gap analysis led to identification of critical components and their respective technology readiness level (TRL)
- Materials compatibility and unique cycle configuration bring key challenges to component development
- Industry engagement critical for component development path forward
- Sandia actively working to improve critical component TRL with industry

	EERE CSP		FE	Nuclear		Preliminary TRL Estimate									
	CSP Indirect	GT bottomin		Sodium SFRs											
Heater															
Exhaust gas/sCO2 heat exchanger		x			Y	X	X	X	X						L
liquid/sCO2 heat exchanger				x	Y	X	X								M
solid/sCO2 heat exchanger	x				Y	X	X	X	by 2016						H
Recuperator(s) (Including recompression)															
below 600 above 400	x	x		x	Y	X	X	X	X	X	X	X	X	X	L
Heat rejection															
dry cooling type	x	x		x	Y	X	X	X	X	X	X	X	X		L
Pipes and Flanges															
Low Temperature Heat Source		x		x	N	X	X	X	X	X	X	X	X	X	L
Higher Temperature Heat Source (>650)	x				Y	X	X	X	X						L
Valves															
Low Temperature Heat Source		x		x	N	X	X	X	X	X	X	X	X	X	L

J. Pasch, M. Carlson, T. Conboy, D. Fleming, A. Kruizenga, J. Neely, *et al.*, "Supercritical CO_2 Power Conversion System (10MW Class): Level 2 Milestone Completion," Sandia National Laboratories, Albuquerque, NM, June 30, 2014

SCO_2 components with low TRL

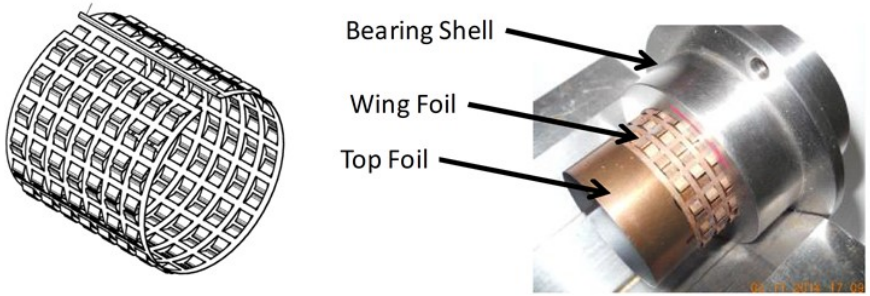
- Heat exchangers
  - Successful collaboration with Vacuum Process Engineering, Inc. (VPE) has increased the TRL while decreasing cost for a domestic manufacturer
- Bearings
  - Ongoing development efforts with Xdot Engineering and Analysis, PLLC on wing foil thrust and journal bearings
- Seals
  - Collaborative partnership with Flowserve, Inc. on dry gas lift-off seals
- High speed motor controllers
  - Not an issue with commercial size systems
  - <1 MW_e difficulty with high speed control

Bearings component development

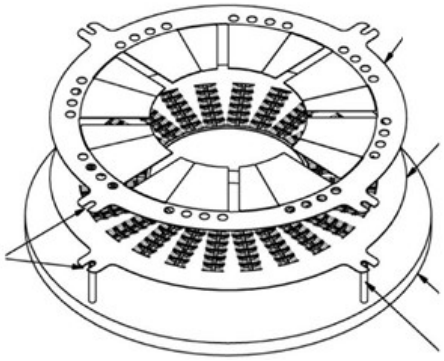
- 400°F (bearing specific)
- 1500 psig
- CO_2 and sCO_2 process gas
- 3.5 kg/s flow rate
- 40,000 rpm

Bearings — status

- CRADA with X-dot has been executed
- Capstone bearings benchmark testing is nearly completed
- Sandia has received X-dot prototype radial bearings for testing
- Sandia is working with X-dot on a thrust bearing design in order to double bearing thrust capacity



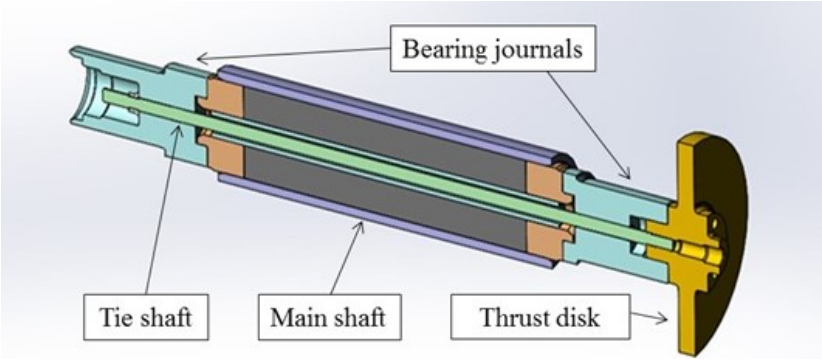
Xdot 1.5” radial bearing

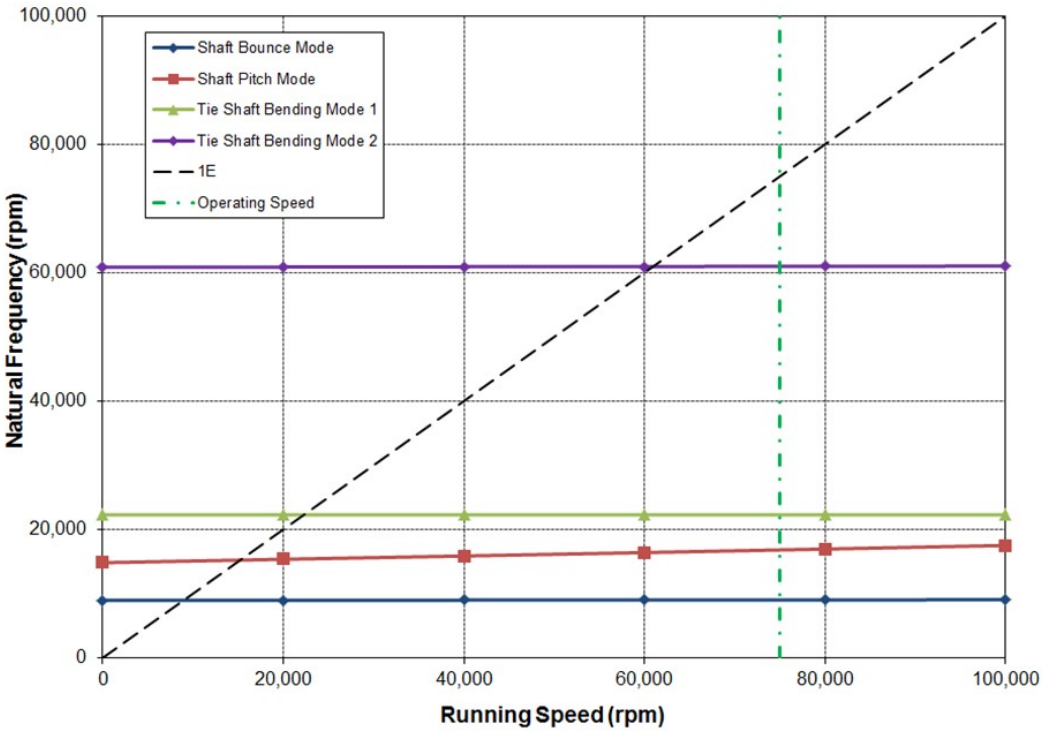


Xdot 3.5” thrust bearing

Rotor dynamics evaluation — bearings test rig assembly

- 4 modes of interest (2 main shaft modes, 2 tie shaft modes)
- Main shaft modes have slightly higher speeds as would be expected
- Shaft modes offer good opportunity to verify bearing properties



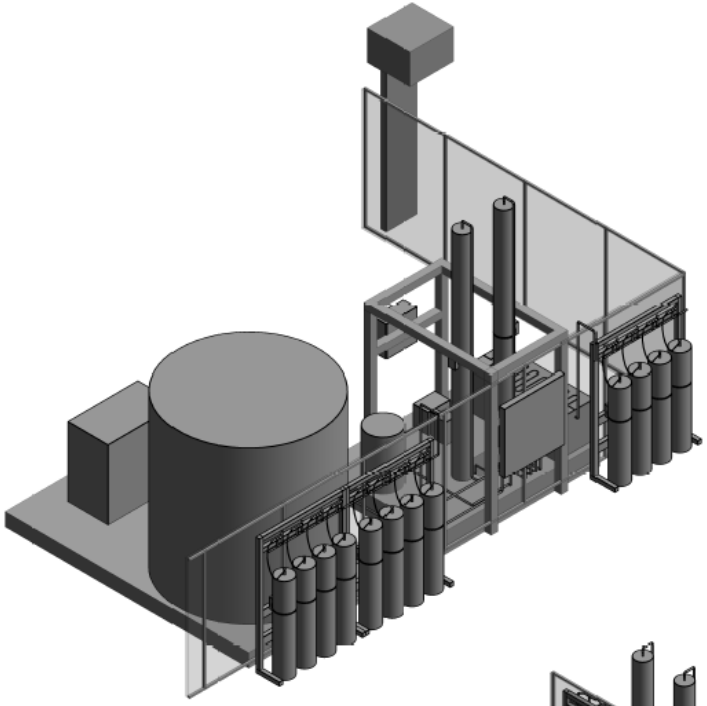


Bearings — technical challenges

- Solvent nature of sCO_2 removes coatings and oils from bearing
- Qualified bearings to operate in a sCO_2 environment

Seals development program

- Collaborating with Flowserve, Inc. on dry gas lift-off seals for sCO_2 Brayton power cycles
- Sandia advancing test capabilities to include turbomachinery seal evaluation at 700°C, 4,400 psi and 40,000 rpm



3D VIEW 1

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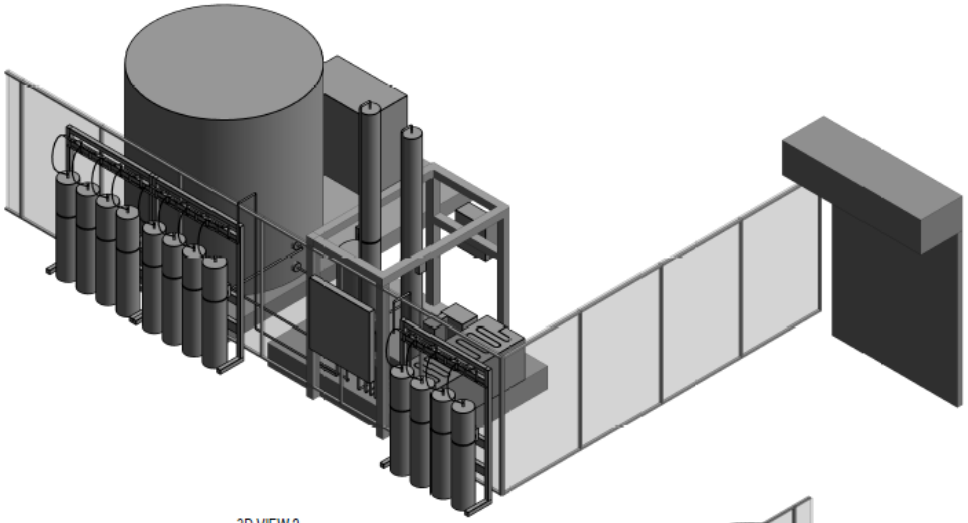

3D VIEW 2

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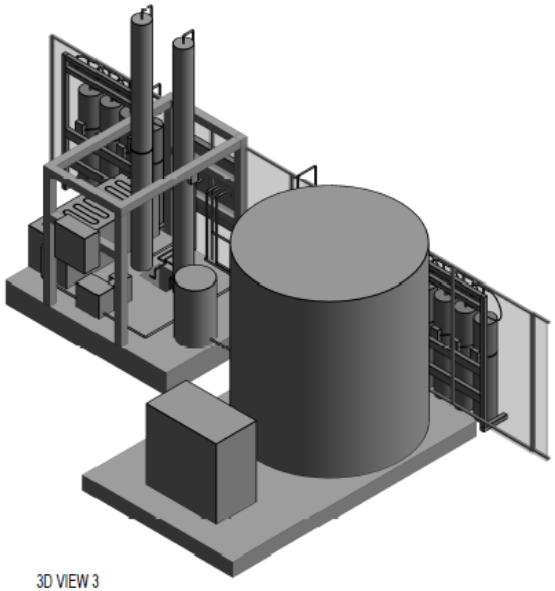

3D VIEW 3

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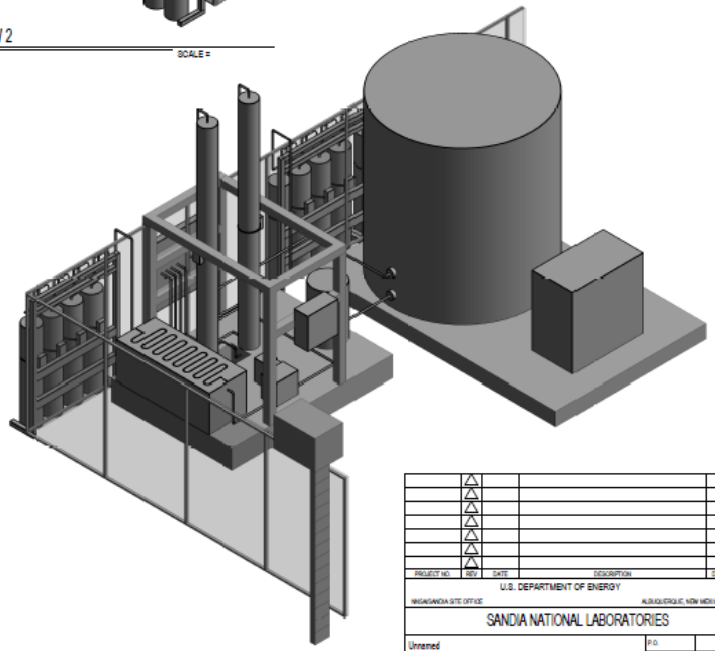

3D VIEW 4

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PROJECT NO.	REV	DATE	DESCRIPTION	DWN	CKD

U.S. DEPARTMENT OF ENERGY

NNSA/SANDIA SITE OFFICE — ALBUQUERQUE, NEW MEXICO

SANDIA NATIONAL LABORATORIES

Unnamed

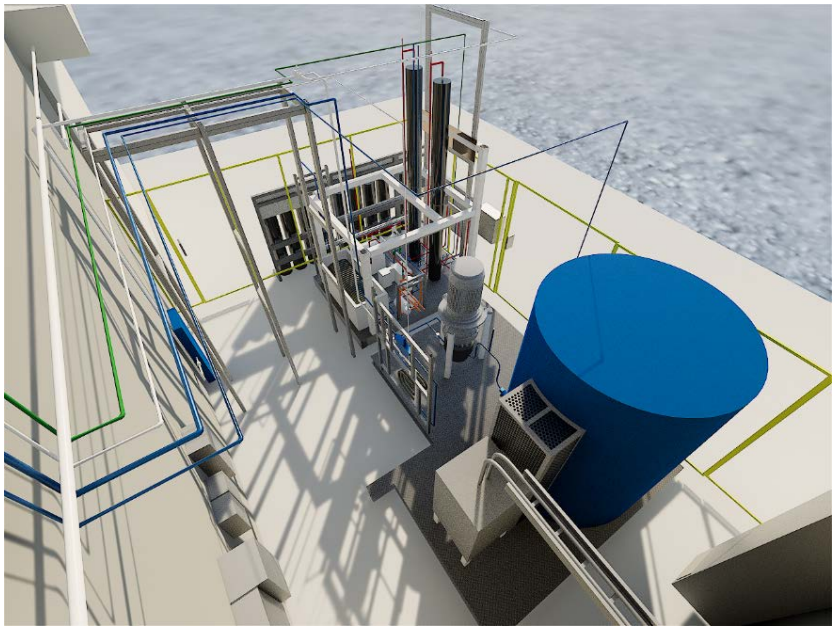
SANDIA NATIONAL LABS
6630 BRAYTON SEAL TEST

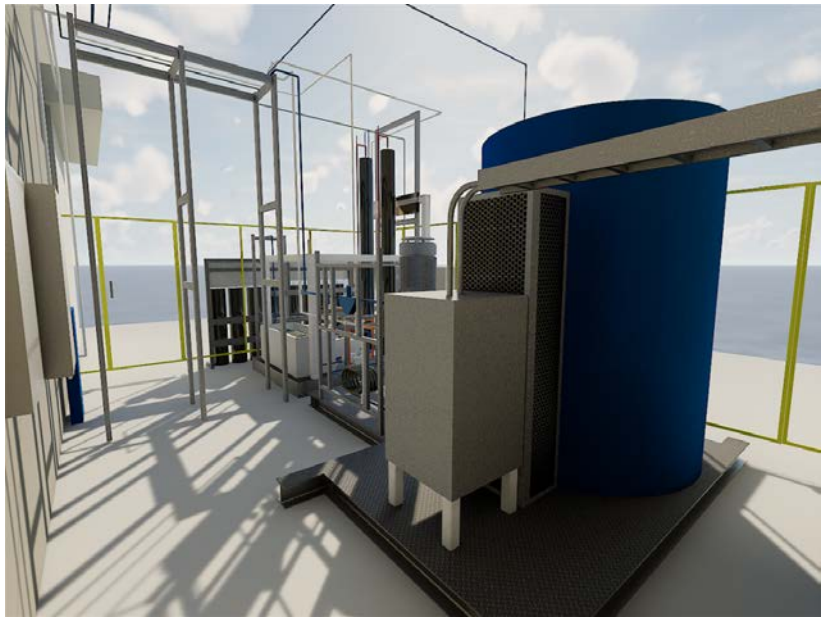
P.O.	
PROJECT NO.	195318
DRAWN BY	Author
CHECKED BY	Checker
ENL ENGR	
DATE	MAY 16, 2016

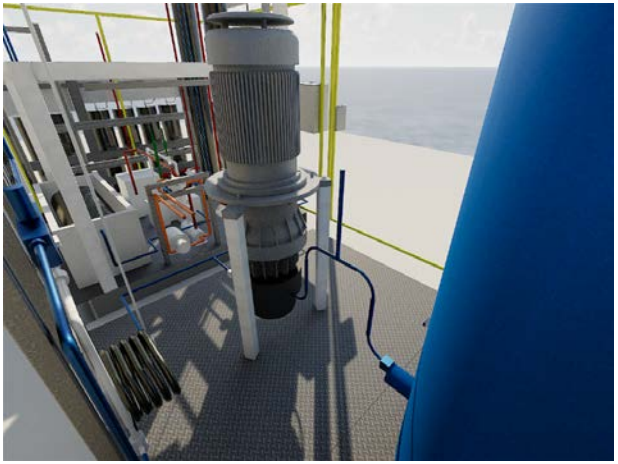
DISCP: SUBDISCP: BUILDING:

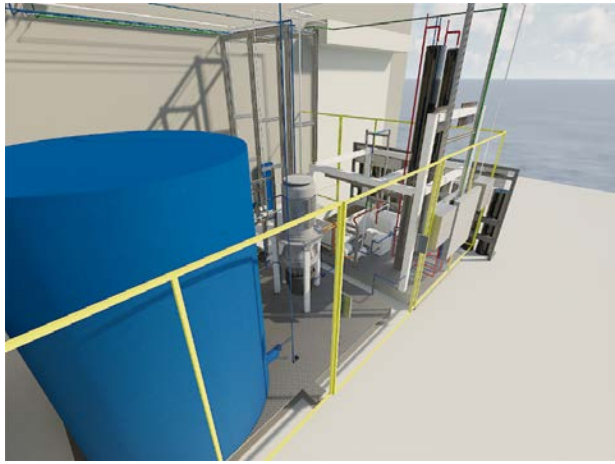
3AEGREEN — SIZE D+ — DRAWING NO SK-M-06 — REV.

Seal test platform renderings









Seals — current status

- CRADA with Flowserve has been executed
- Development of Seals test rig is well underway
- Flowserve has designed a seal to test sCO_2 at 700°C and 4400 psi
- Heater is ordered
- Various consulting contracts have been placed
- Test rig has been designed and final FEA is complete

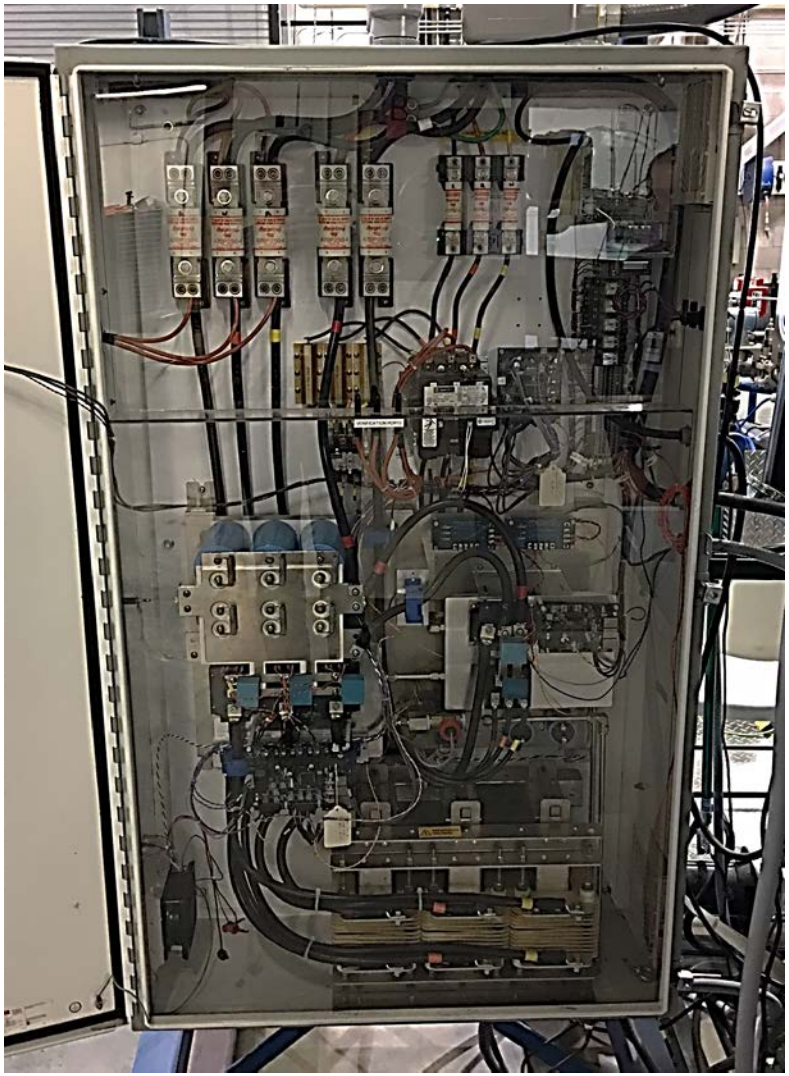
Seals — technical challenges

- High temperature materials are needed to get to the 700°C inlet temperature of Turbine
- High leakage rates using sCO_2
- Qualified seals to operate in a sCO_2 environment

Motor controller — technical challenges

- Instability in shaft speed/power for one of a kind motor controllers
- High speed switching leads to failure of IGBT switches
- Smaller than 1 MW_e machines have to operated in excess of 75,000 rpm so permanent magnet rotors are used

Sandia sCO_2 RCBC motor controller



Summary

For systems < 1 MW_e, technical challenges remain in advancing TRL for critical components

Bearings: Bearings development has been progressing at SNL and by the end of the calendar year we will have demonstrated two bearings qualified for s-CO2 service.

Seals: Seals development platform will be commissioned Jan. 2018 and the first of a kind HT seal will be demonstrated in s-CO2

Motor controllers: Advanced motor controllers have not been identified because at larger power levels they are not needed.

Questions?

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