SAND2016-2751C

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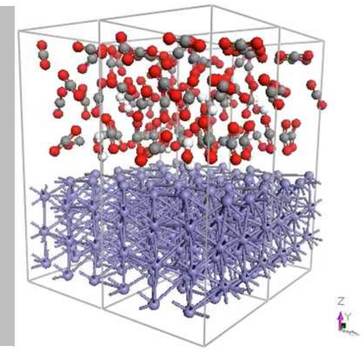

sCO2 Brayton Research at Sandia National Laboratories

J. Pasch, D. Fleming, M. Carlson, M. Walker, A. Kruizenga, G. Rochau

U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration

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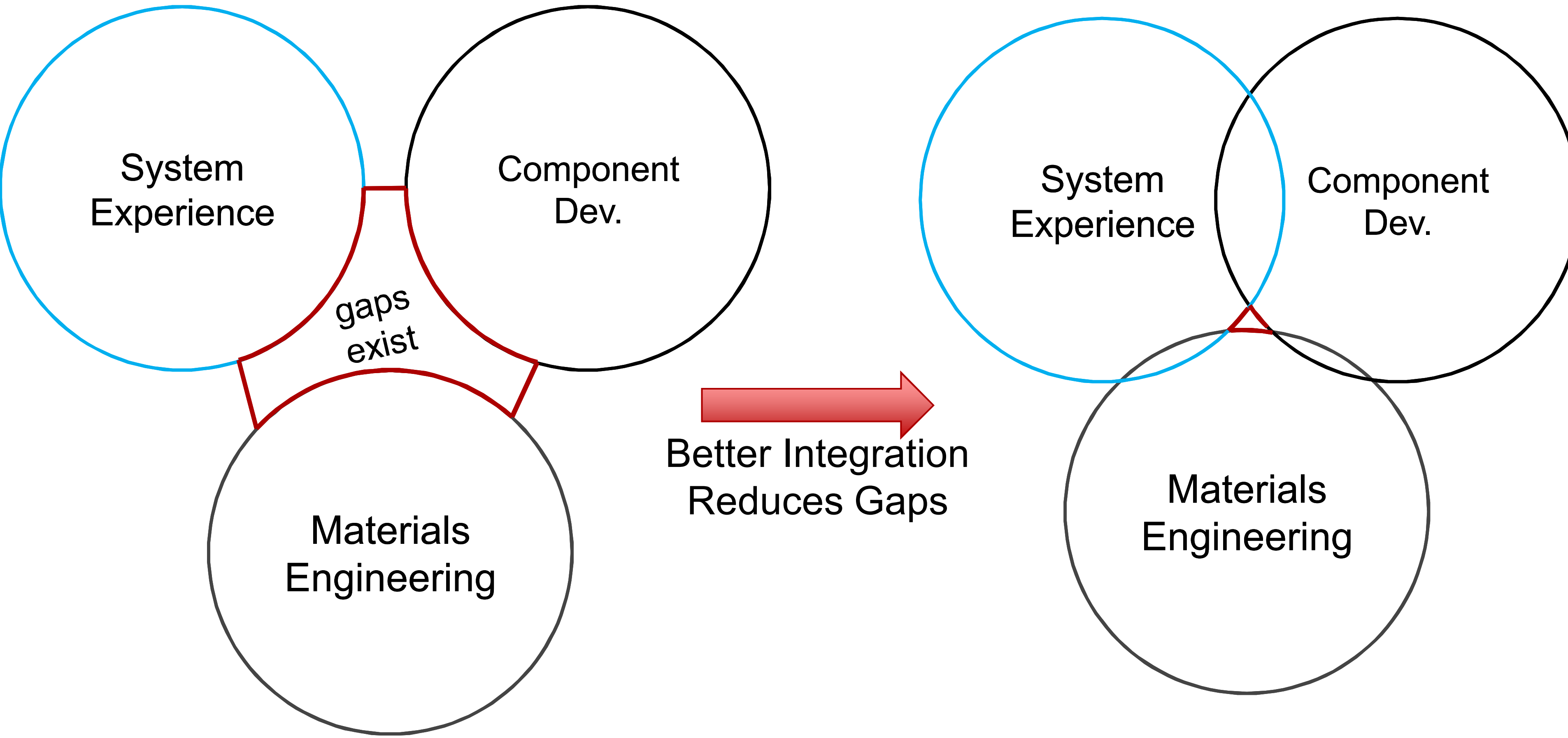
Sandia Lab Brayton Strategy

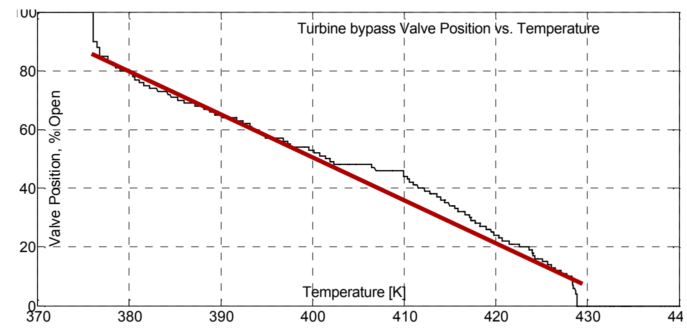
Sandia National Laboratories

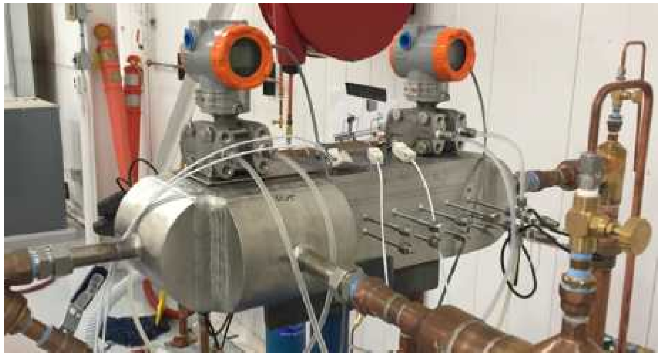


Current Progress

System Experience:

- Recent tests achieved two primary conclusions:
  - Robust heat rejection system operations for various climates
  - Turbine/compressor models predict experimental performance
- Establish procedures for pre-test, start-up, and ramp-up
  - Reliable procedures for standard operations
- Root Cause Analysis as tool to refining system operations



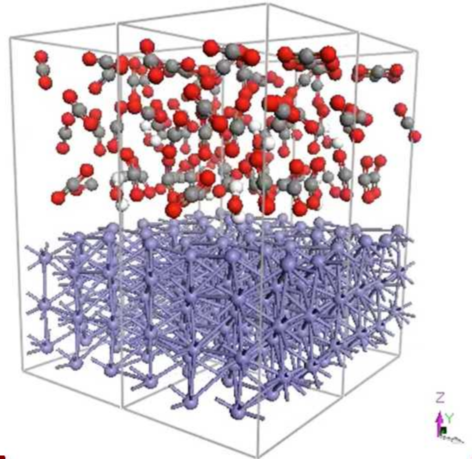


Component Development: Tools and Test Facilities

- Heat Exchanger Test platform: water-to-water up to $100kW_{th}$
  - Collaborations continue to prove out different PCHE designs
- Building a bearing and seals test platform
- Advanced methods to understand wear/performance
  - Computed Tomography for turbomachinery wear

Materials Engineering:

- Fundamental models: simulations aide mechanistic interpretation
  - Molecular dynamics (MD) of ferrous/nickel rich alloys baseline behavior
- Economic Optimization: carbon steel in sCO2 up to 260^{o}C



Future Efforts and Thoughts

System Experience:

- Continue collaborative development of RCBC as Pilot Test System
  - Prove out performance through testing (component/system)
  - Baseline system model validation: steady state and transient
  - Develop control algorithms with components test rig
  - Dry Cooling: assess performance and operational effects

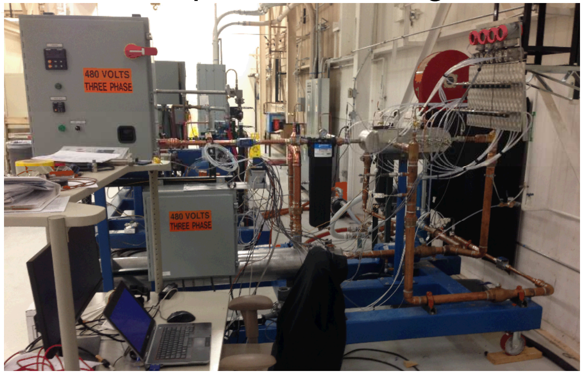
Component Development: Tools and Test Facilities

- Verify performance of component using test facilities:
  - Heat Exchanger Development
  - Turbomachinery Development
  - Bearing Development
- Work with industry to overcome technological hurdles:
  - Leverage SNL test platforms with third party hardware testing

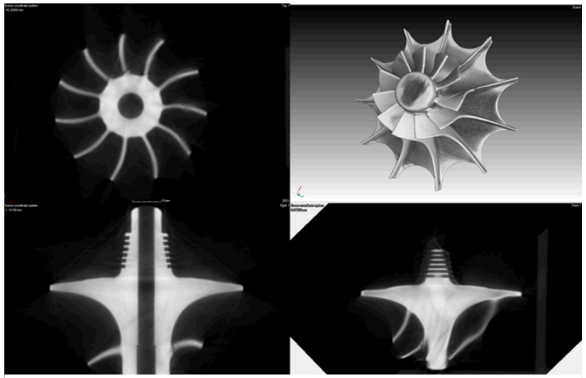
Materials Engineering:

- Evaluate materials for bearing applications
- Leverage thermochemical and MD modeling:
  - Understand system chemistries
  - V&V with appropriate experiments
- sCO2 Materials Engagement need to be formalized:
  - FE-EERE-NE along with University and Industrial Partners
  - AUSC experience is a great model for this process

Components test rig

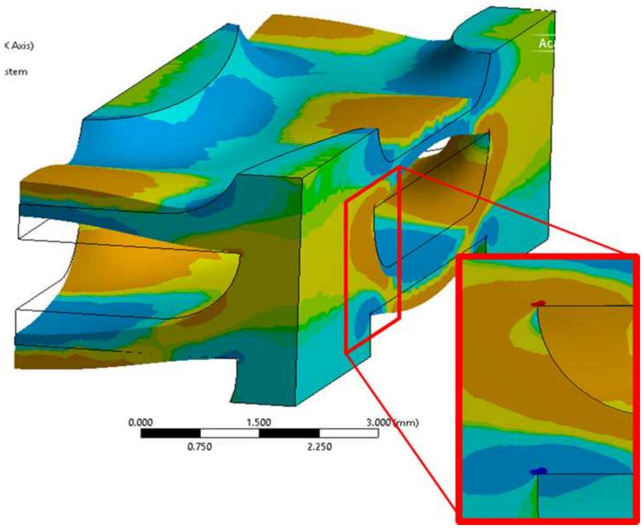


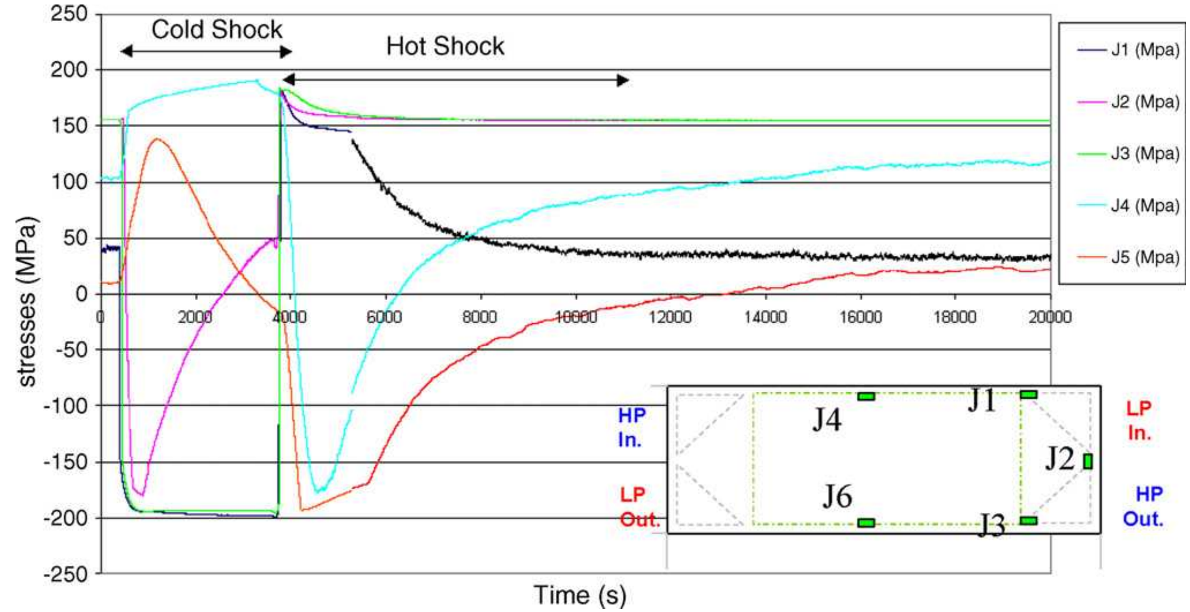
Heat Exchanger test rig

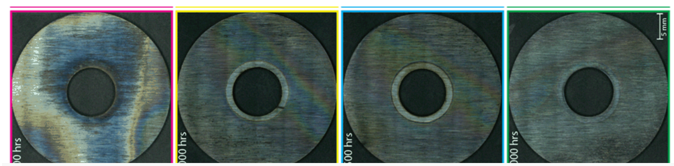


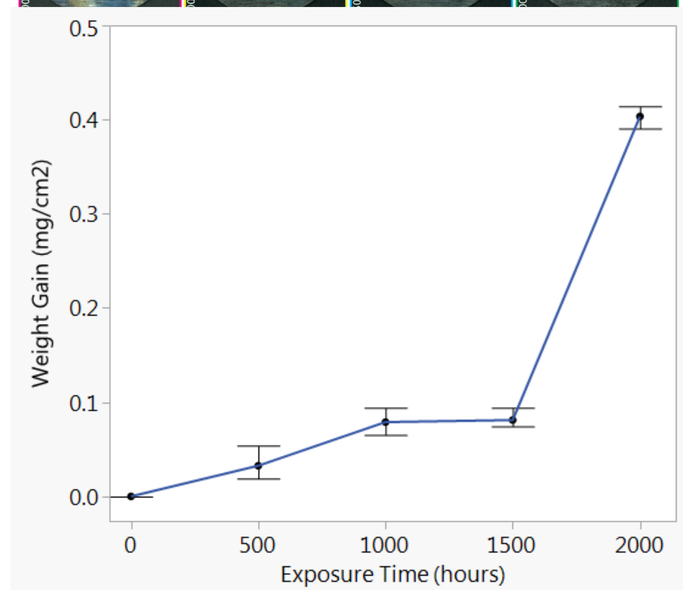
Turbines Radiography

Back ups


0.000
1.500
3.000 (mm)
0.750
2.250


Cold Shock
Hot Shock
stresses (MPa)
Time (s)
J1 (Mpa)
J2 (Mpa)
J3 (Mpa)
J4 (Mpa)
J5 (Mpa)
HP In.
LP Out.
LP In.
HP Out.
J1
J2
J3
J4
J6




Weight Gain (mg/cm2)
Exposure Time (hours)

PROGRAMMATIC DIRECTION

Heat Exchanger Development Gaps

Technology Readiness Levels		from Direct Gas Combustion	from Exhaust Gas	from 3 MPa Helium	from Steam	from floride molten salts	from nitrate molten salts	from liquid sodium	from liquid lead-bismuth	from Heat Transfer Oil	from Combusting Particles	from Inert Solid Particles	from Geothermal Resources	from sunlight	Yet To Be Identified Materials	Advanced Nickel Alloys	Conventional Nickel Alloys	Austenitic Stainless Steels	to Water	to Humidified Air	to Dry Air	TIT / °C
Molten Salt Reactor	NE					3											4-5	6-8	6-8	2	2-4	700 to 850
Sodium Fast Reactor (SFR)	NE							3										6-8	6-8	2	2-4	550
Lead Fast Reactor (LFR)	NE								3								4-5	6-8	6-8	2	2-4	550 to 800
Helium Gas Reactor (GFR, VHTR)	NE			4-5											2	3	4-5	6-8	6-8	2	2-4	700 to 1000
Nuclear Shipboard Propulsion	NE																	6-8	6-8			200 to 300
Direct CSP Tower	EE													4-5			4-5	6-8	6-8	2	2-4	500 to 1000
CSP Tower with Thermal Storage	EE						3	2		2		3					4-5	6-8	6-8	2	2-4	500 to 1000
CSP Trough with Thermal Storage	EE						3			2								6-8	6-8	2	2-4	300 to 600
CSP Dish Generator	EE							2		2				4-5			4-5	6-8			2-4	500 to 1000
Direct Geothermal Plant	GT												2					6-8	6-8	2	2-4	100 to 300
Indirect Geothermal Plant	GT				4-5													6-8	6-8	2	2-4	100 to 300
Direct Natural Gas Combustion	FE	3-5	4												2	3	4-5	6-8	6-8	2	2-4	1100 to 1500
Integrated Gasification Coal	FE	3-5													2	3	4-5	6-8	6-8	2	2-4	1100 to 1500
Pulverized Coal Fluidized Bed	FE										4					3	4-5	6-8	6-8	2	2-4	550 to 900
Waste Heat Recovery	FE		4															6-8	6-8	2	2-4	230 to 650
Gas Turbine Bottoming	FE		4															6-8	6-8	2	2-4	230 to 650
Municipal waste to energy	FE		4															6-8	6-8	2	2-4	230 to 650
10 MWe Pilot	FE		4														4-5	6-8	6-8	2	2-4	550 to 700
50 MWe Demonstration	FE		4														4-5	6-8	6-8	2	2-4	550 to 700
		N/A	Gas			Liquid					Solid				>750	750	650	550	sCO2 Cooling			
		sCO2 Heating from Various Sources													Recuperation MDMT / °C							

Development Gaps Addressed

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Technology Readiness Levels		from Direct Gas Combustion	from Exhaust Gas	from 3 MPa Helium	from Steam	from floride molten salts	from nitrate molten salts	from liquid sodium	from liquid lead-bismuth	from Heat Transfer Oil	from Combusting Particles	from Inert Solid Particles	from Geothermal Resources	from sunlight	Yet To Be Identified Materials	Advanced Nickel Alloys	Conventional Nickel Alloys	Austenitic Stainless Steels	to Water	to Humidified Air	to Dry Air	TIT / °C
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CSP Dish Generator	EE							2		2				4-5			4-5	6-8			2-4	500 to 1000
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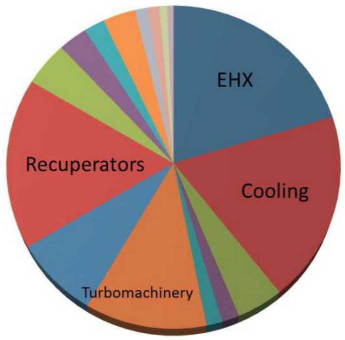
		N/A		Gas				Liquid					Solid		>750	750	650	550	sCO2 Cooling			
		sCO2 Heating from Various Sources													Recuperation MDMT / °C							

NE, Peregrine CRADA | NEUP | NEUP | SuNLaMP | SERIIUS | NE, NEUPs | NEUP, APOLLO, NE, CRADAs (VPE, Peregrine)

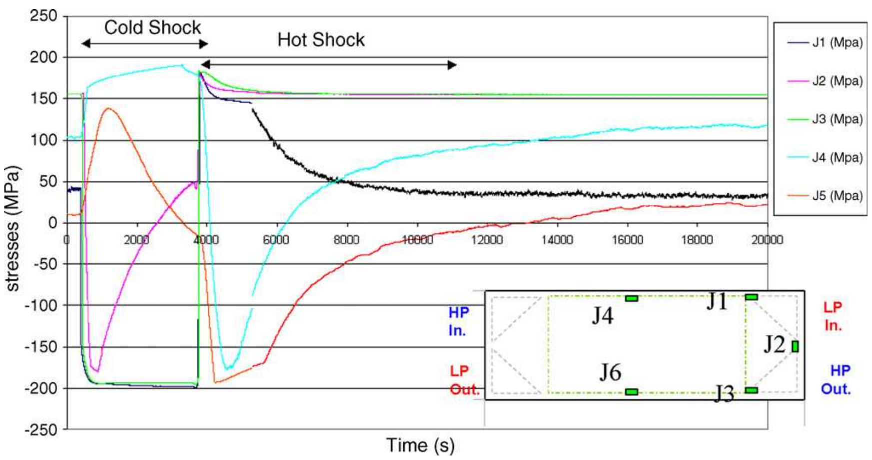
Key Development Metrics

- **Economics**
  - How do we optimize designs and reduce fabrication costs?
    - Efficiency vs. Effectiveness
    - Efficiency vs. pressure drop
    - Manufacturing techniques
- **Failure Modes**
  - How do we accommodate thermal stress and fatigue?
    - Pressure containment (material vs. geometry)
    - Higher Temperatures
    - Corrosion and fouling

Echogen



"[A] 30% reduction in HX cost would have [a] meaningful impact on system cost."



STEP R&D PCHE Tasks

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1. Flow Optimization
2. Shim Fabrication
3. Alternative Headers
4. Failure Modes
5. HT Enhancement
6. Geometric Strength
7. High-Temp Bonds
8. Dissimilar Metals

Tasks 1–4: With VPE CRADA Partnership

Task 4: With FY16 CINR RC-2.1 (if awarded)

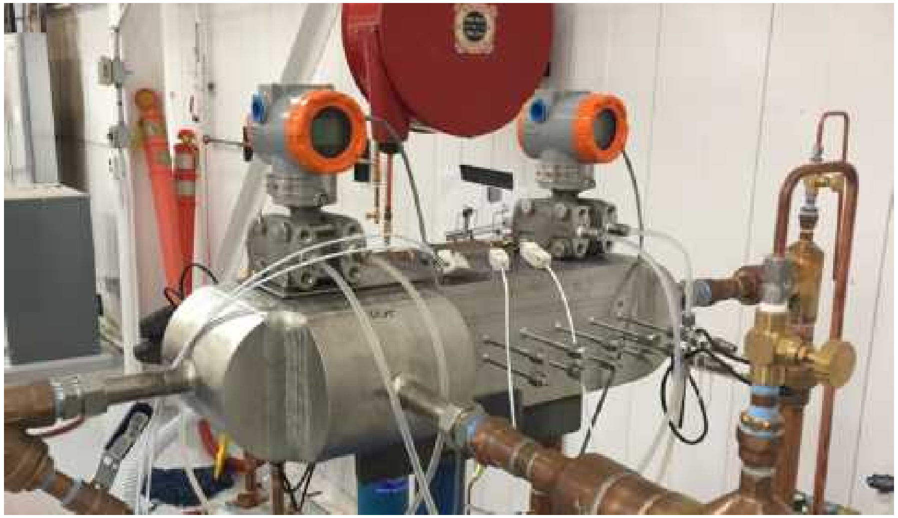
Task 5: With NEUPs 13-5101 and 14-6670

Task 6: With NEUPs 13-5101 and 14-6670

Tasks 7–8: FY17-18 research partly in partnership with VPE through the CRADA

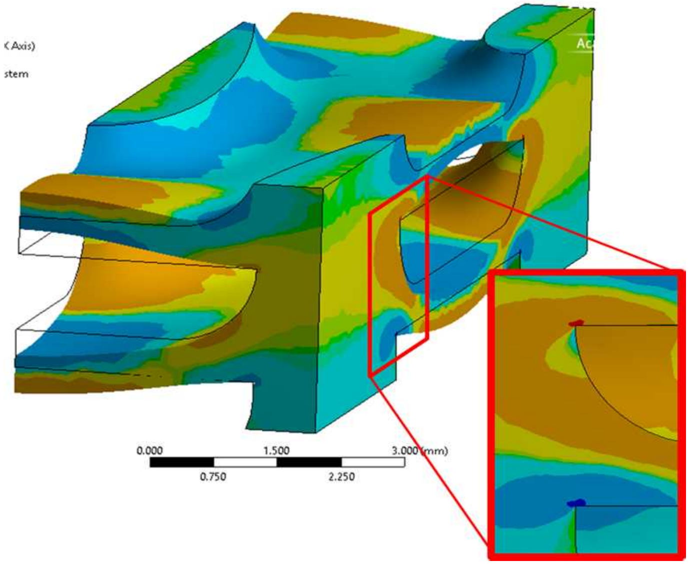
VPE CRADA Partnership

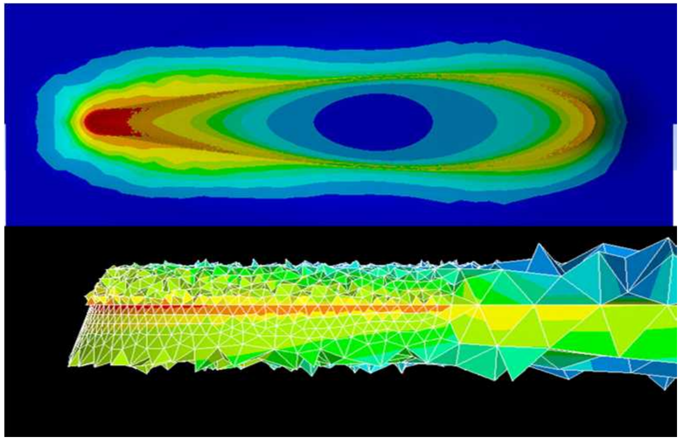
1. Flow Optimization
2. Shim Fabrication
3. Alternative Headers
4. Failure Modes
7. High-Temp Bonds
8. Dissimilar Metals



ART and NEUP Collaborations

4. Failure Modes
5. HT Enhancement
6. Geometric Strength





SuNLaMP Particle/sCO2 HXer

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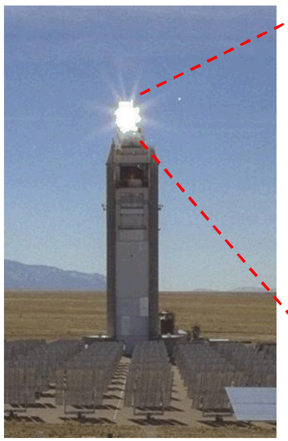
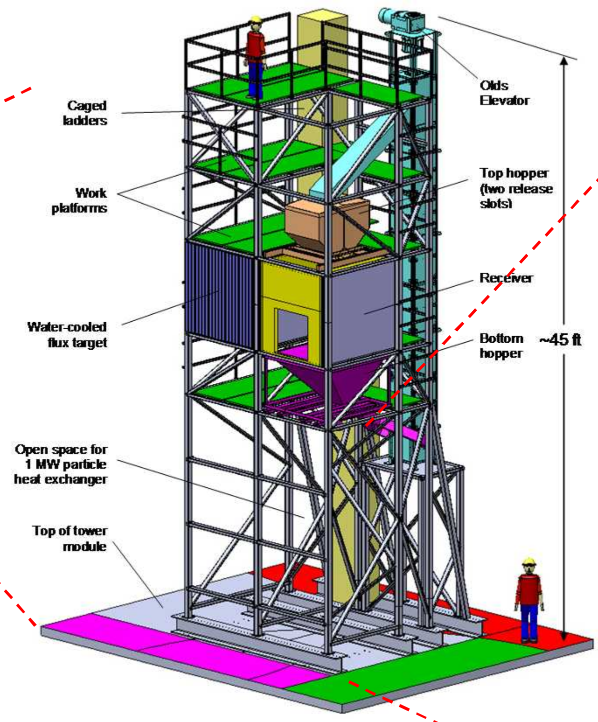
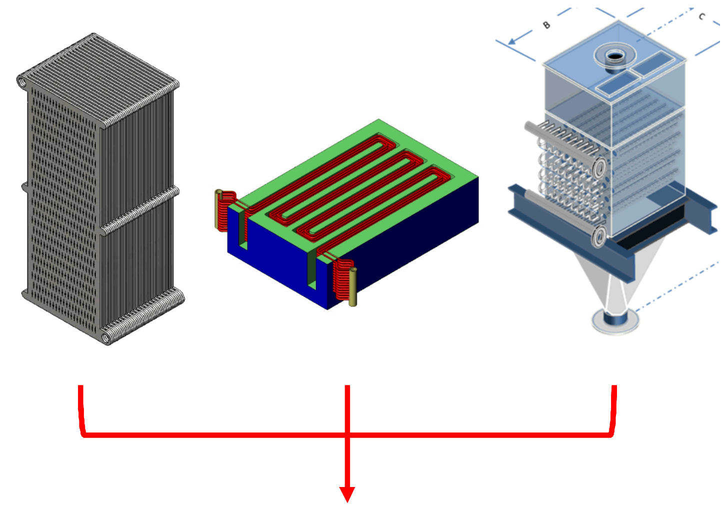
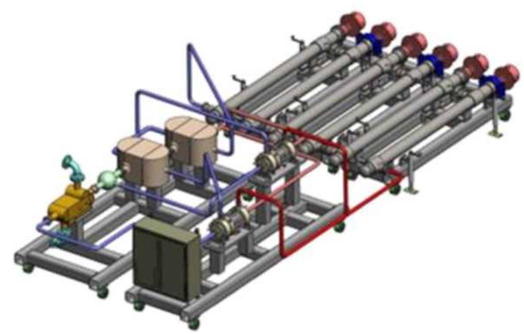




Particle Receiver

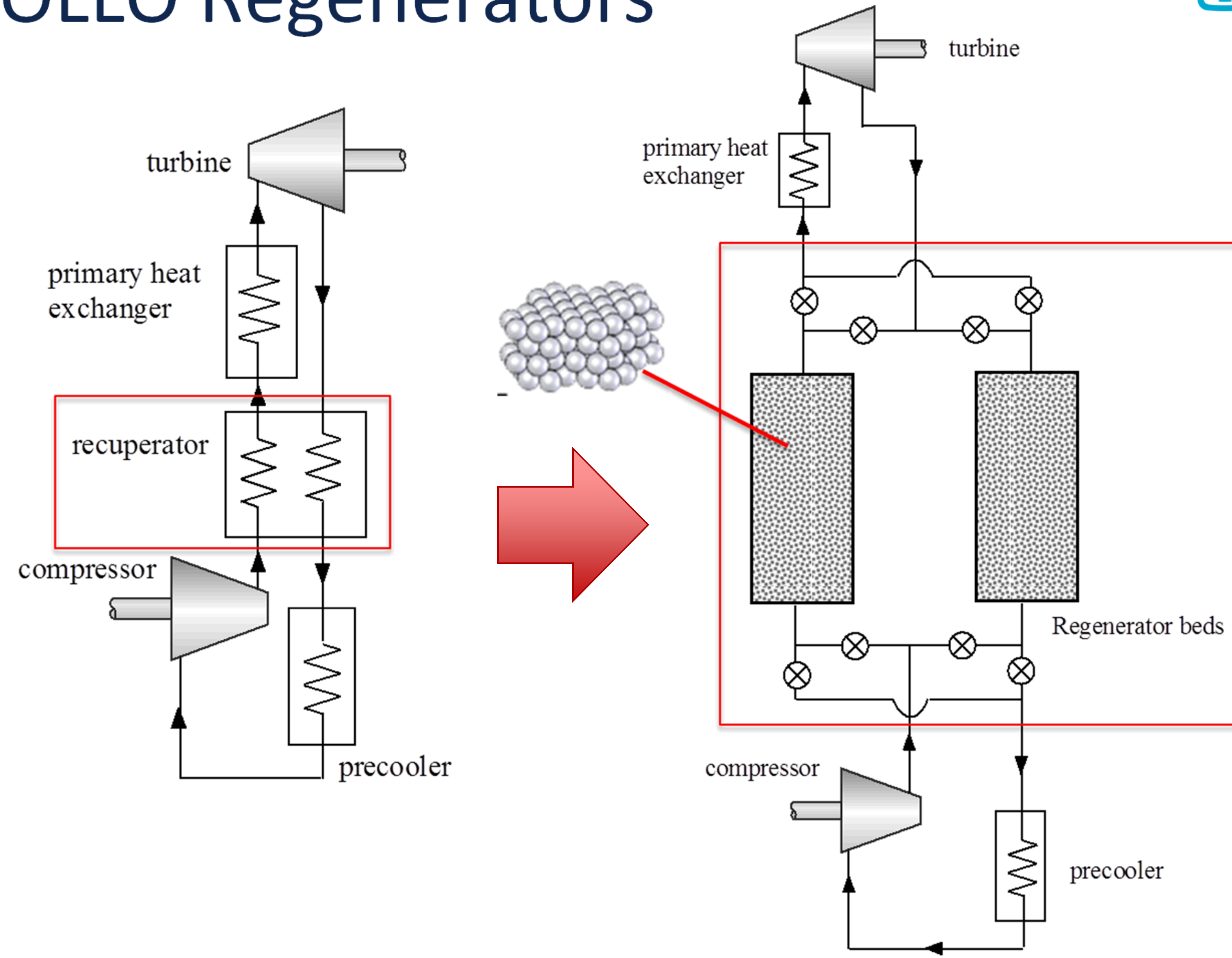
Particle/sCO2 HX





sCO2 Flow System

APOLLO Regenerators



UNM NEUP Twisted Tube HXers