U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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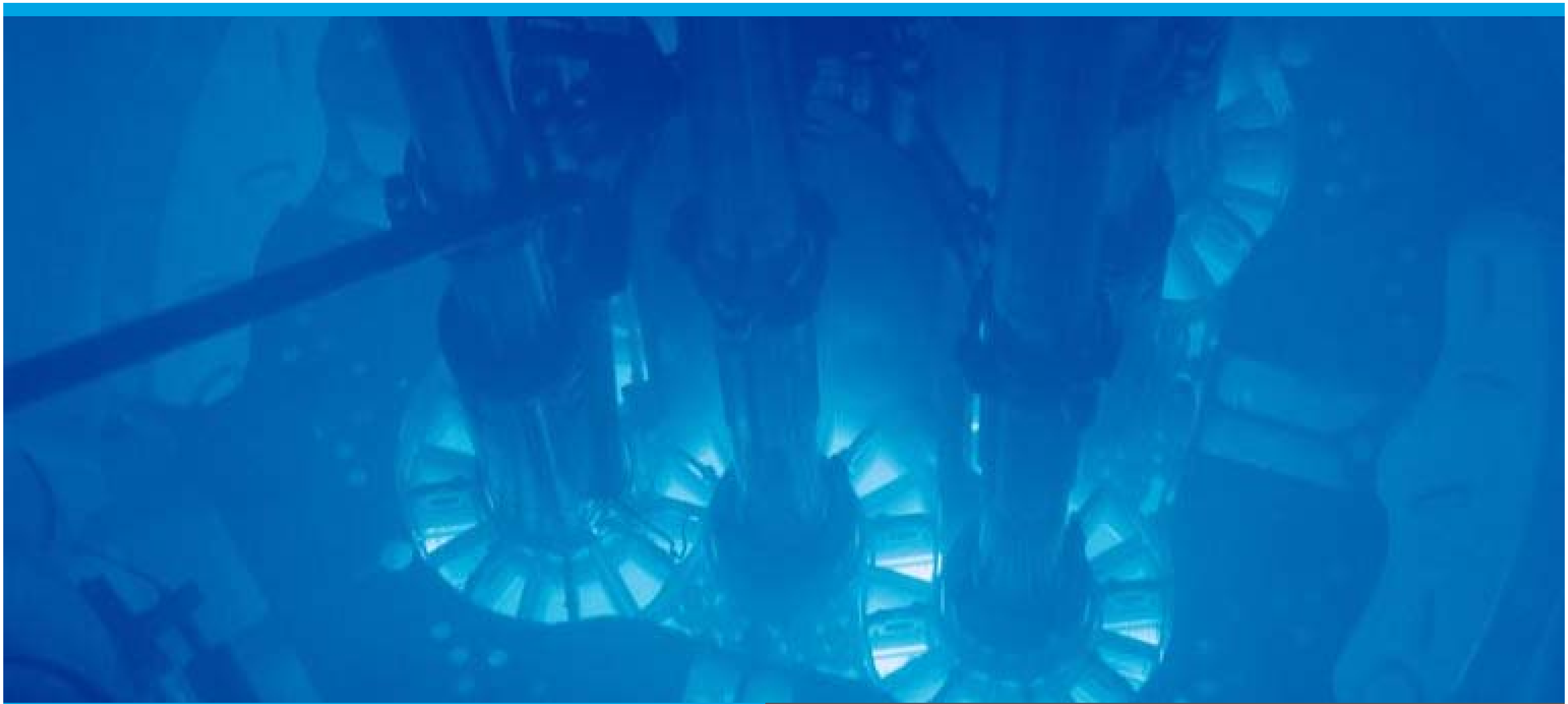

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Associate Deputy Assistant Secretary
for Nuclear Technology Research and Development

Supercritical Carbon Dioxide (sCO_2) Power Cycles for Advanced Reactor Technologies

Presidential and Departmental Nuclear Energy Priorities

– President Trump ordered review of nuclear energy policy:

“[W]e will begin to revive and expand our nuclear energy sector… which produces clean, renewable and emissions-free energy. A complete review of U.S. nuclear energy policy will help us find new ways to revitalize this crucial energy resource.”

– Commercialization of advanced SMRs crucial to future of US nuclear sector

– White House National Security Strategy:

"We will improve America’s technological edge in energy, including nuclear technology, next-generation nuclear reactors..."

– Executive Order Promoting Energy Independence and Economic Growth

– Nuclear energy role as clean baseload power is key to environmental challenges:

“If you really care about this environment that we live in… then you need to be a supporter of this [nuclear energy] amazingly clean, resilient, safe, reliable source of energy.” Secretary Rick Perry at Press conference, May 10th

– Make nuclear cool again and inform citizenry regarding nuclear energy’s attributes

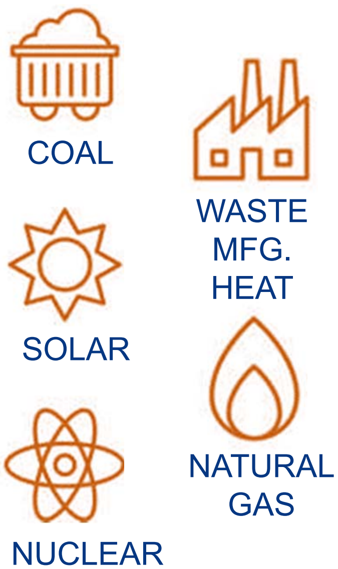
– Waste Policy: Restarting Yucca process and developing interim storage capability

Comprehensive Civil Nuclear Energy Policy Review

Four Tracks

1. Preserve the existing fleet, with a focus on stopping premature shutdowns of reactors.
2. Restore U.S. nuclear R&D capabilities and enable innovation in new reactors.
3. Establish a plan to increase global market share.
4. Resolve uncertainty on waste, reprocessing, enrichment, medical isotopes.

Supercritical CO_2 Power Cycles Applications



Diverse fuel/ heat sources

Supercritical CO_2 a highly efficient working fluid

Higher thermal efficiencies, smaller physical footprint, and lower capital costs
(than conventional steam-based power generation)

Cleaner, more affordable electricity

Nuclear Energy – sCO_2 Cycle Motivation and Approach

- **Key to future advanced reactor deployments is improved economics**
  - Reduced capital cost
  - Reduced operations and maintenance costs
  - Improved performance

- **NE initially focused on Sodium Fast Reactor (SFR) application**
  - Target commercialization of the sCO_2 system in an SFR by 2030
  - Assumes Recompression Closed Brayton Cycle (RCBC) at a turbine inlet of 550 C
  - Establish capabilities for integrated system testing to increase component TRLs
  - Establish dynamic system models
  - Explore chemical and material interactions between sodium and sCO2

- **Establish partnerships with industry to advance systems and components for use in higher temperature nuclear reactor concepts**
  - High Temperature Gas Cooled Reactors and Molten Salt Reactors (up to 750 C)

Nuclear Energy sCO_2 Energy Conversion Program

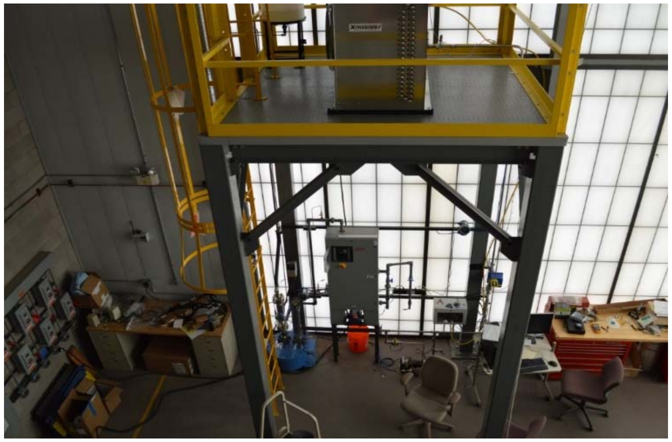
2007-2009	• **Low Temp. sCO_2 Brayton Cycle Simple Test-Loop Built and Initial Operation**
2010	• Condensing sCO_2 Brayton Cycle Compression Demonstration
2011	• Qualification of Gas-Lubricated Foil Thrust Bearings
2012	• **Heatric High Temperature PCHE Recuperator installed**
2013	• Advanced SFR sCO_2 Power Conversion with Dry Cooling Developed
2014	• Technology Risks Identified for SFR Energy Conversion
2015	• **Full RCBC at 550C Commissioned and Established Industry Partnerships**
2016	• Strategic Partnership Projects and Cooperative R&D Agreements with Industry to Support DP at SNL
2017	• Technology Roadmap Developed to Support a Pilot Demonstration by 2020
2018	• **Development Platforms for Industry for Heat Exchangers, Seals, Bearings, and Turbomachinery**

Critical Investments in Infrastructure: Development Platforms

- **Established component development platforms for:**
  - Turbomachinery
  - Natural Circulation
  - Seals & Bearing
  - Heat Exchangers & Headers
  - Materials
  - Chemical interactions
  - Dynamic Modeling & System Integration

Lab-scale test Article Turbo-compressor

Compressor/ Seal Test Loop



Natural Circulation Loop

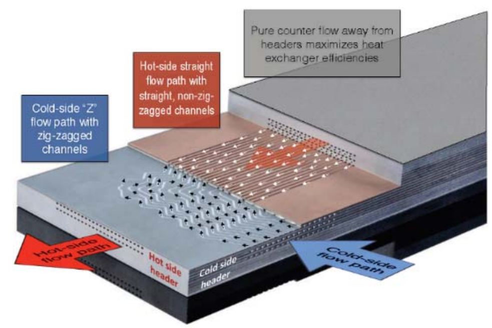
Development Platforms (continued)

Heat Exchanger Development

- Developed SEARCH software and instrumented test loop
- Established CRADA with Vacuum Process Engineering

Results

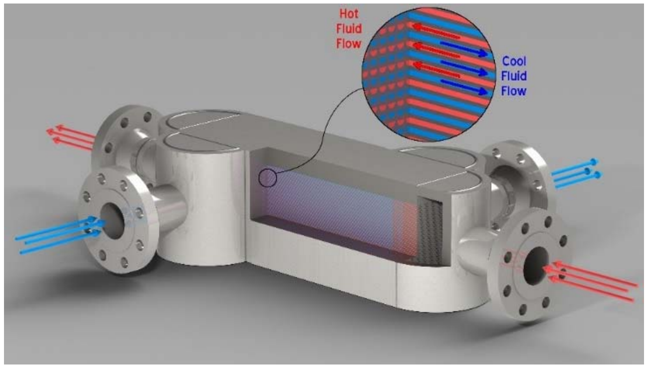
- Technology Transfer Award
- ASME Certification of VPE micro-channel HEX manufacturing



SEARCH Licensed
(FLC 2016 Tech Transfer Award)

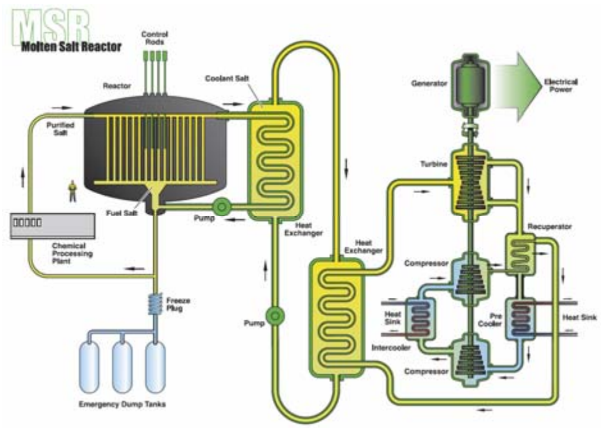
Worlds Largest Bonder

Heat Exchanger Test Loop



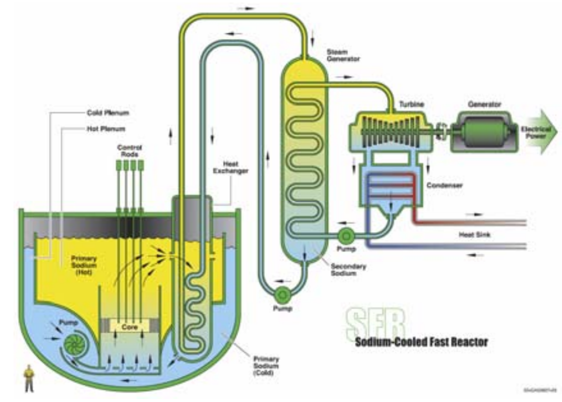
Code-Stamp

Partnership Mechanisms



SBIR - Comprex
Large-shim
Diffusion Bonding

NEUP - UNM
Double-Walled
Twisted Tube HEXs

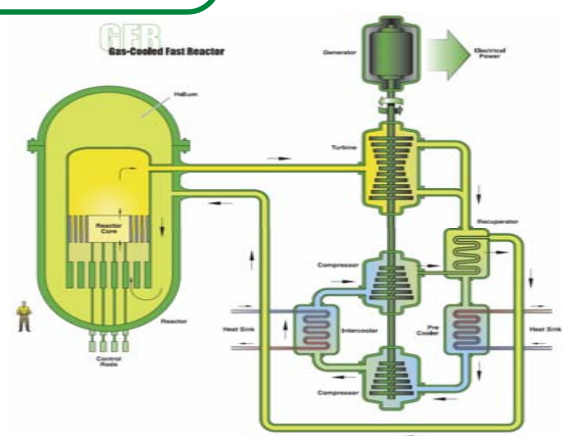


NEUP- UW-Madison
sCO2-cooled
Space Reactor

Technology Comm. Fund
Optimized Headers

CRADA - VPE
Design, Shims,
Headers, Lifetime

IRP- UW-Madison
Compact HEXs for
Nuclear Applications

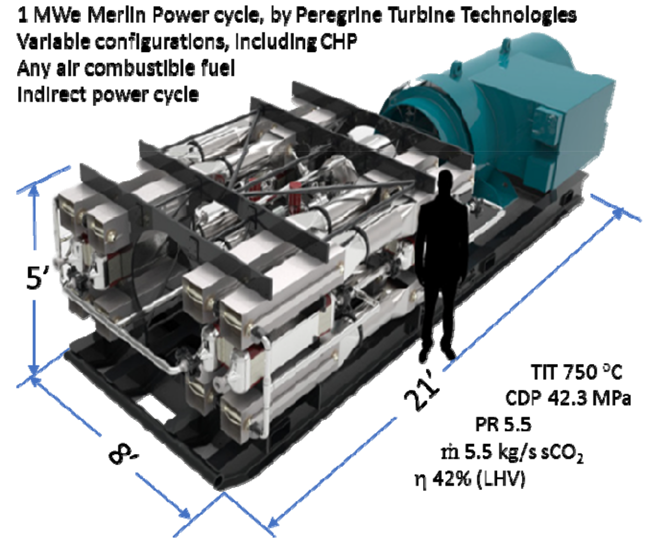


Funding Opportunities
DE-FOA-0001817
U.S. Industry Opportunities for
Adv. Nuclear Tech. Dev.

NEUP - GA-Tech
ASME-III Qualification
of Diffusion Bonding

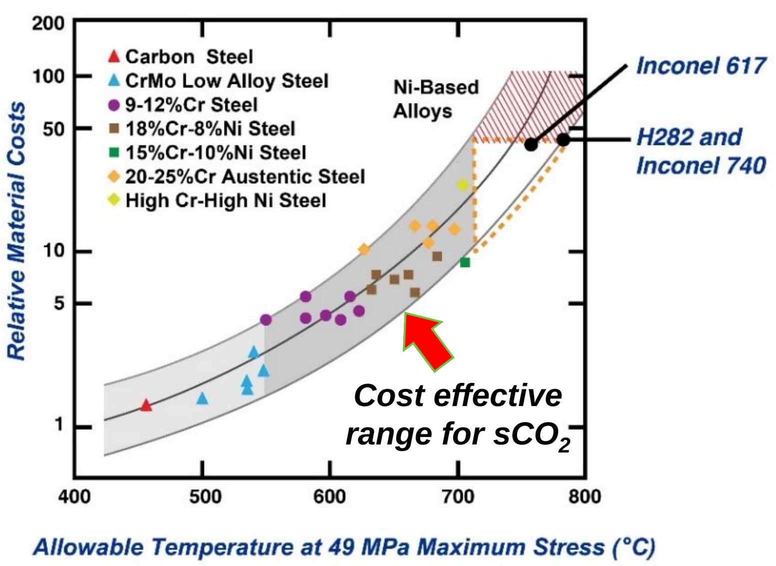
Key Areas of Research: **Turbomachinery**

- **Goal:** Develop suitable designs for higher temperatures and power densities of CO2 power cycles
- **Challenge:** Process conditions challenge current bearing and seal designs
- **Path forward:** Working with labs, industry, program offices to optimize designs for performance, cost, and durability.
    - Testing 1 MWe system
    - Initiate redesign RCBC DP reliable parallel compression testing
    - Long-term testing under various operating conditions

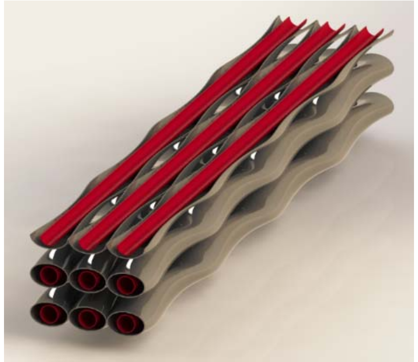


Key Areas of Research: **Materials**

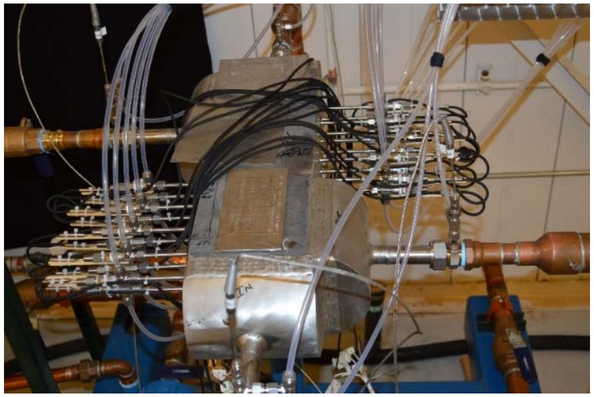
- **Goal:** develop low-cost materials compatible with sCO_2 under extreme process conditions
- **Challenge**: Temperatures >700 C and 300 bar challenge today's super alloys. Lower-cost, high-performing materials and manufacturing techniques are needed for long-term durability
- **Path forward:** Design, develop, quantify, and certify materials and to accelerate advanced manufacturing and joining techniques
  - Develop an sCO_2 materials consortium
  - Coupon testing at elevated pressures and temperatures



Key Areas of Research: **Recuperator / Heat Exchanger**



- **Goal:** Develop low-cost, compact heat exchangers to handle higher temperatures and differential pressures
- **Challenge**: current designs require expensive manufacturing and materials to transfer heat efficiently while also tolerating high temperature and pressure differentials.
- **Path forward:** Work with labs and industry to develop new manufacturing techniques and explore new component designs to improve performance
  - Perform larger scale testing of diffusion bonds
  - Complete sodium-CO_2 interaction experiments
  - Continue lifetime testing and new materials for PCHE



Key Areas of Research: **Systems Analysis/Modeling**

- **Goal:** Assess sCO_2 process viability in today's competitive market
- **Challenge:** More data is needed on fluid properties under extreme, atypical conditions to validate models and optimize critical systems
- **Path forward:** Collaborate with industry, labs, and other partners to obtain relevant test data
    - Initial public release of Plant Dynamic Code
    - Develop modeling tools and optimize RCBC parameters for LCOE
    - Utilize development platforms to acquire performance data

http://computation.llnl.gov/catalyst-supercomputer

Conclusions

- **Improved economics and performance are essential to the future expansion of nuclear energy technologies**
- **The sCO_2 power cycle has the potential to offer higher efficiency and lower cost across a wide range of applications**
- **The Office of Nuclear Energy will partner with industry, academia and other stakeholders to accelerate innovative technology development**

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