U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Interest in Supercritical CO_2 Power Cycles for Nuclear Energy Applications

5th International Symposium on sCO_2 Power Cycles

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Outline

- Nuclear's role in the clean energy portfolio
- Transition to the nuclear fleet of the future
- Nuclear technology innovation
- R&D activities on sCO_2 power cycles
- Summary

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Policy Drivers that support the Expansion of Clean Energy

- **Climate Action Plan – June 2013**
  - Reduce greenhouse gas emissions by 30% by 2030
- **Executive Order #13693 - March 19, 2015**
  - Reduce Federal facility greenhouse gas emissions 40% by 2025
  - Defines "clean energy" to include alternative energy
    - Definition of “alternative energy” includes “small modular nuclear reactor technologies”
- **Clean Power Plan – August 3, 2015**
  - Sets CO_2 emissions performance goals for every State in U.S.
  - Provides flexibility to States to choose how to meet carbon standards
    - Include renewables, energy efficiency, natural gas, **nuclear** and carbon capture and storage
- **COP21 – December 12, 2015**
  - International agreement to limit average temperature rise to <2°C
  - Reaffirmed U.S. commitment to carbon reduction goals

Nuclear Power: A Sustainable Clean Power Source

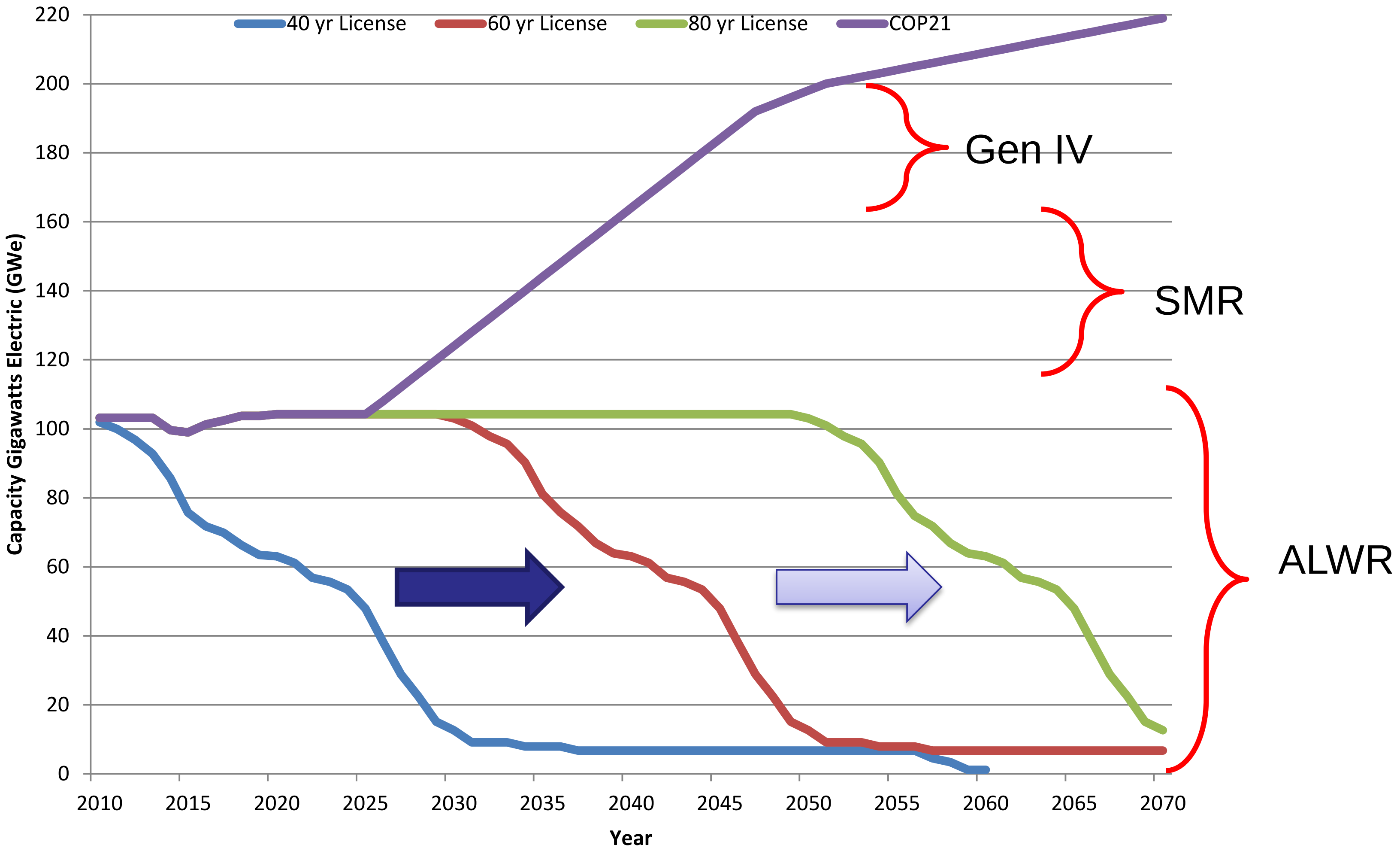
"To meet our emissions reduction targets and avoid the worst effects of climate change, we need to dramatically reduce power sector emissions. Switching from coal to natural gas is already reducing the U.S. carbon footprint, but it's not enough to get the deep CO_2 cuts envisioned in the President's Climate Action Plan. Reducing emissions by 80% will likely require the complete decarbonization of the power sector….

Secretary Moniz
COP21, Paris 2015

We know <u>nuclear can provide 24-hour baseload power</u>, because it already does. Worldwide, nuclear power produces more energy than hydro, solar, wind, and geothermal power combined.

The bottom line is that to achieve the pace and scale of worldwide carbon reductions needed to avoid climate change, <u>nuclear must play a role</u>."

Nuclear Power Capacity needed to meet Clean Power Goals



Growing National Interest in Advanced Reactors

- **There is a growing interest in the development and deployment of advanced (non-light water) nuclear reactor technologies**
  - According to Third Way, there are 48 companies in North America, backed by >$1.6 billion in private capital developing plans for advanced nuclear reactors (Jan 2016 Summit and Showcase)
  - The Administration recently emphasized support for nuclear as an essential part of the All of the Above clean energy strategy (Nov 2015 White House Convening)
  - Bi-partisan support in both Houses of Congress for advanced nuclear technologies as evidenced by recent Bills and appropriations higher than the President's request.
- **DOE-NE is conducting an Advanced Test/Demonstration Reactor Study as directed by Congress in the FY2015 Omnibus Spending Bill**
- **Secretary of Energy Advisory Board Task Force on the Future of Nuclear Power is examining the possibility of a major new deployment of nuclear power, to include advanced reactors, in the 2030-2050 time period**
- **NRC-DOE Joint Workshops on Advanced Non-Light Water Reactors**

Gateway for Accelerated Innovation in Nuclear

What are the Problems/Issues?

- Time to market for nuclear technology is too long.
- Facilities needed to conduct the necessary RD&D activities are very expensive to develop and maintain.
- Capabilities (e.g., facilities, expertise, materials, and data) at government sites have not been easily accessible by the entities trying to commercialize innovative systems and components.
- Technology readiness levels vary – requiring differing research and funding opportunities.
- Many technology developers require assistance working through the regulatory process for new nuclear technologies.

What do we need to do?

- Provide nuclear innovators and investors with a single point of easy access to the broad range of capabilities – people, facilities, materials, and data – across the DOE complex.
- Provide focused research opportunities and dedicated industry engagement, ensuring that DOE-sponsored activities are impactful to stakeholders working to realize the full potential of nuclear.
- Expand upon DOE's work with the Nuclear Regulatory Commission (NRC) to assist technology developers through the regulatory process.

What is the DOE initiative?

- Public-private partnership headquartered at INL
- Dedicated to accelerated commercial readiness of innovative technologies

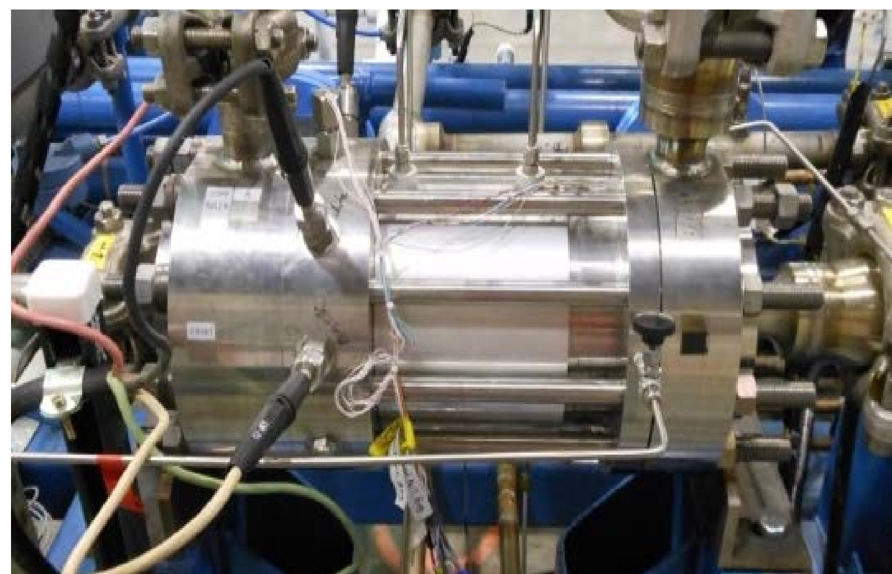
Government Assets:

- Tens of $B in DOE and partner assets *(experimental and computational)*
- Multi-$B in yearly investments for R&D and infrastructure
- $12.5 B in loan guarantees
- Small Business vouchers
- Expertise *(thousands of FTE/yr.)*

GAIN
Gateway for Accelerated Innovation in Nuclear

Current Activities to Develop sCO_2

- **Component and material development and testing**
- **Dynamic plant modeling and validation**
- **Analytical studies (performance, cost, system integration)**
- **Stakeholder engagement and strategic industry partnerships**
- **System integration studies using Recompression Closed Brayton Cycle Test Article at Sandia National Laboratories (since early 2010)**



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sCO_2 Development Platforms

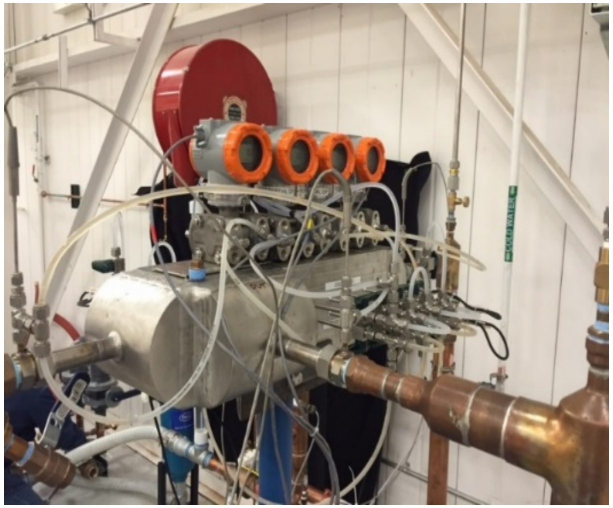
Leverage existing National Laboratory sCO_2 development platforms/capabilities to develop and refine components and address technical risks to wide-scale commercial deployment

sCO_2 Bearings, Seals and Compressor research platform

sCO_2 Natural Circulation Test rig

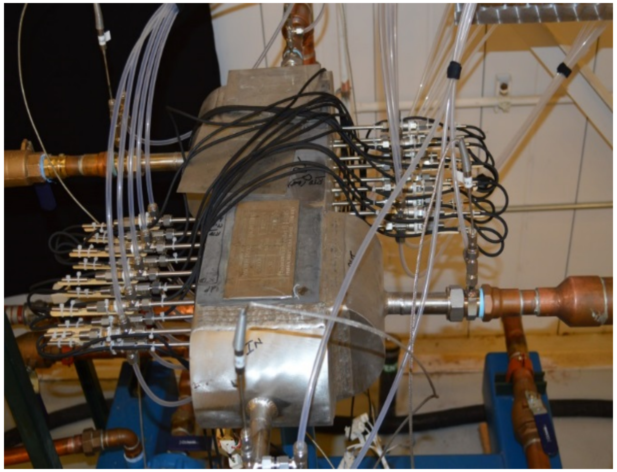
Compact Heat Exchanger R&D

Compact, high performance and economical heat exchangers are vital to achieving the full benefit of sCO2 cycles in nuclear applications



Accomplishments:

- Industry engagement led to ASME qualified manufacture of diffusion bonded PCHE
- Developed and verified a new thermal hydraulic performance code (SEaRCH)



Next Steps:

- Evaluate component performance (*pictured*)
- Qualify additional HEX materials
- Study material corrosion/erosion behaviors
- Pursue ASME Code qualified HEX designs
  - Dry-cooled sCO_2 power for Advanced Reactors
  - CO_2-Sodium HEX that can support Advanced Reactors

sCO_2 Modeling

- **Accurate "real time" models are needed to optimize power cycle design and operation**
- **Models need to accurately predict cycle behavior during the full range of system evolutions**
  - Normal operations, start-up/shutdown, load following, off-normal transients
  - Need to be validated against actual test, experiment and operational data
- **Plant Dynamics Code provides insights for scale-up to larger nuclear applications**
  - State-of-the-art tool for system level transient analysis
  - Good agreement between Plant Dynamics Code and test data
- **Additional codes/models are used to incorporate advanced control theory methodologies using data from Sandia's test article for validation**
  - SEaRCH (Selection, Evaluation and Rating of Compact Heat Exchangers)
  - GPASS – Development is centered on the transient effects from a nuclear reactor
  - FUEGO – Computational Fluid Dynamics model for sCO_2 natural circulation
- **sCO_2 Cycle Control Strategy Development for use with Sodium Fast Reactor**
  - Current work focuses on control strategy that addresses load following from 100 to 0 % nominal power and removes decay heat down to less than 1% level
  - Future work includes investigation of advanced control theory methodologies beginning with investigation of sensor response time lag effects

Summary

- Nuclear energy is an important element of the future energy mix and innovative technologies are needed to meet the demand of the decarbonized world.
- The potential benefits of the sCO_2 Brayton Cycle for nuclear power applications have been explored for over a decade
- This technology offers an opportunity to dramatically change the energy landscape
- There is a strong sense of urgency to develop and deploy innovative technologies to address climate change
- Private sector engagement and involvement is essential

Backup Material

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NE FY 2017 Congressional Request Funding Summary

(Dollars in Thousands)

	FY 2015 Enacted	FY 2016 Enacted	FY 2017 Request
Integrated University Program	**5,000**	**5,000**	**0**
SMR Licensing Technical Support	**54,500**	**62,500**	**89,600**
STEP R&D	**5,000**	**5,000**	**0**
Reactor Concepts RD&D	**133,000**	**141,718**	**108,760**
Fuel Cycle R&D	**197,000**	**203,800**	**249,938**
Nuclear Energy Enabling Technologies	**101,000**	**111,600**	**89,510**
Radiological Facilities Management	**25,000**	**24,800**	**7,000**
Idaho Facilities Management	**206,000**	**222,582**	**226,585**
Idaho Sitewide Safeguards and Security	**104,000**	**126,161**	**129,303**
International Nuclear Energy Cooperation	**3,000**	**3,000**	**4,500**
Program Direction	**80,000**	**80,000**	**88,700**
Total, Nuclear Energy	**913,500**	**986,161**	**993,896**