Commercializing the $sCO_2$ Recompression Closed Brayton Cycle

Gary E. Rochau, (505) 845-7543, gerocha@sandia.gov
6221 Advanced Nuclear Concepts
Nuclear Energy Systems Laboratory/Brayton Lab (ne.sandia.gov/nesl)
Pathway to “Technology Commercialization”

Scientific Discovery

Brayton Cycle Power Cycle Concept

Gas Brayton Power Cycles

Supercritical Brayton Power Cycles

High Efficiency Brayton Power Generators

2nd Law of Thermodynamics (Carnot 1824)

Ready Engine (Brayton 1872)

Closed Air Brayton Cycle (Ravensburgh, 1956)

sCO2 Recompression Closed Brayton Cycle (Sandia National Laboratories, 2014)

Gov. R&D

Shared Cost

Ind. Development

Commercial Brayton Generators

R&D Optimized Brayton Cycle Demonstration ~2022

Simple Brayton Cycle Pilot Demonstration ~2022

R&D Foundational Demonstration ~2019

Discovery

Laboratory Scale

Prototype/Pilot

Industrialization

General R&D

Specific R&D

Development
Sandia’s Energy Conversion Program

• SNL’s high-efficiency thermal-energy-conversion objective is to:
  • Lead to science-to-engineering solutions
  • High-efficiency heat-to-electricity conversion
  • Limit the use of fresh water
• Develop supercritical closed Brayton cycle technology by:
  • Solving materials-science challenges,
  • Applying system engineering,
  • Integrating and up-scaling existing technology, and
  • addressing operational-control challenges at or near the critical point of fluids
Recompression Closed Brayton Cycle (RCBC) Test Article (TA) at Sandia National Labs

- TA under test since 4/2010
- Over 100 kW-hrs of power generated
- Operated in 3 configurations
  - Simple Brayton
  - GE Waste Heat Cycle
  - Recompression
- Verified cycle performance
- Developed Cycle Controls
- Progressing toward power generation
- Developing maintenance procedures

**TA Description:**
- **Heater** – 750 kW, 550°C
- **Max Pressure** - 14 MPa
- **TACs** – 2 ea, 125 kWe @ 75 kRPM, 2 power turbines, 2 compressors
- **High Temp Recuperator** - 2.3 MW duty
- **Low Temp Recuperator** – 1.7 MW duty
- **Gas Chiller** – 0.6 MW duty
- **Load Bank** – 0.75 MWe
- **Gas Compressor** to scavenge TAC gas
- **Inventory Control**
- **Turbine Bypass** (Remote controlled)
- ASME B31.1 Coded Pipe, 6 Kg/s flow rate
- **Engineered Safety Controlling Hazards**
- Remotely Operated
DOE Laboratory R&D Partnerships

SNL Solar Test Facility

SNL Brayton Laboratory

UW-Madison Stress Corrosion

SNL Materials Chemistry

SNL Surface Materials & Coatings

SNL Tribology

ANL Material Corrosion Lab

ORNL Advanced Structural Materials
Status of the Commercial Development Effort

- **Proof of Concept S-CO$_2$ loops**
  - SNL, Echogen, KAPL-Bettis, Czech Republic, Japan, GE-GRC

- **Gas Turbine Bottoming Cycle**
  - 3 Corporations; 10 MWe

- **Solar Towers**
  - 2 Corporations; 1-10 MWe

- **Carbon Capture & Sequestration**
  - 3 Corporations, 5, 7, 70 MWe

- **Waste Heat Recovery**
  - 3 Corporations
SNL/DOE Design Target for Proof-of-Principle Split-Flow Re-compression S-CO$_2$ Brayton Cycle

High Density Means Very Small Power Conversion System  
Non-Ideal Gas Means Higher Efficiency at Moderate Temperature

- **Circle 1:** 
  - Temperature: $T=305$ K
  - Pressure: $P=7690$ kPa
  - Efficiencies: $\eta = 0.66$
  - Work: $126$ kW

- **Circle 2:** 
  - Temperature: $T=324$ K
  - Pressure: $P=13842$ kPa
  - Work: $178$ kW

- **Circle 3:** 
  - Temperature: $T=389$ K
  - Pressure: $P=13727$ kPa
  - Work: $87$ kW

- **Circle 4:** 
  - Temperature: $T=698$ K
  - Pressure: $P=13612$ kPa
  - Work: $213$ kW

- **Circle 5:** 
  - Temperature: $T=810$ K
  - Pressure: $P=13499$ kPa
  - Work: $2.58$ kg/s

- **Circle 6:** 
  - Temperature: $T=750$ K
  - Pressure: $P=7885$ kPa
  - Work: $126$ kW

- **Circle 7:** 
  - Temperature: $T=418$ K
  - Pressure: $P=7820$ kPa
  - Work: $3.46$ kg/s

- **Circle 8:** 
  - Temperature: $T=350$ K
  - Pressure: $P=7755$ kPa
  - Work: $2.3$ kg/s

---

**Notes:**
- **He Turbine (300 MWe)**
- **S-CO$_2$ (300 MWe)**
- **Steam Turbine (250 MWe)**
- **High Efficiency at Lower Temp (Due to Non-Ideal Gas Props)**
- **High Efficiency at Lower Temp (Due to Non-Ideal Gas Props)**
- **Waste Heat Coolers 531 kW**
- **783 kW Heaters**
- **319 kW Low temp HX**
- **2232 kW High temp HX**
- **610 kW Low temp HX**

---

**Cycle Efficiencies vs. Source Temperature**

- CO$_2$, RCBC, reheat, intercooling
- CO$_2$, simple CBC
- SMR operating range
Supercritical CO₂ Cycle Applicable to Most Thermal Sources

Solar

Nuclear (Gas, Sodium, Water)

DOE-NE Advanced Reactors

Supercritical CO₂ Brayton Cycle

Waste Heat Chiller

ARRA Geothermal

Gas Turbine Bottoming

Gas

CONUS Marine Mobile?

Fossil Sequestration Ready

Clean Coal & Natural Gas Power Systems

SunShot Power Cycle

Military
Sandia’s Mission Focus

- **Brayton Mission**
  - “By the end of FY 2019, Sandia National Laboratories shall develop, with industry, a fully operational 550°C-10 MWe R&D Demonstration SC\(\text{O}_2\) Brakey Power Conversion System that will allow the systematic identification and retirement of technical risks and testing of components for the commercial application of this technology.”

- **System Attributes**
  - **Re-configurable** to allow the testing of commercially attractive configurations and system components that can be transferred to industry
  - **Formally applied systems engineering** in the identification and retirement of technical risks in a phased approach
    - Phase 1: to first proceed from the existing 150KWe system to the 10 MWe-550°C system
    - Phase 2: to higher power levels and temperatures after 2019
  - **Demonstrate SNL’s capability** to systematically:
    - Apply graded approach using applicable scientific and engineering rigor
    - **Address development and maturation risks of commercially viable technologies** for putting power on the grid, reducing the use of water, reducing carbon emissions, and/or reducing capital costs based on “industry pull.”
Commercialization Approach

- **Broaden Industrial Engagement in R&D**
  - Identify industrial stakeholders through Federal Business Opportunities to seek “funds-in” CRADAs for technology development
  - Offer IP portfolio for licensing
  - Use NE program funds/facilities to address technical risks expressed by industry
  - Recognizing R&D capabilities of SNL and utilizing facilities

- **Demonstrate Foundational Technology**
  - At the highest possible temperature with code qualified materials
  - At the highest practical power level that leads to a pilot demonstration and “market pull”

- Initial engagements will build a foundation to a “R&D consortium” for advancing the TRL level for larger scale and higher temperature demonstrations
  - Primary Funding from Industry – Industry design role
  - Seed money from DOE – System Integration, demonstration, and evaluation
  - Government use licensing

- DOE support “might” end at Pilot Scale Demonstration