SAND2012-9090P

Exceptional service in the national interest

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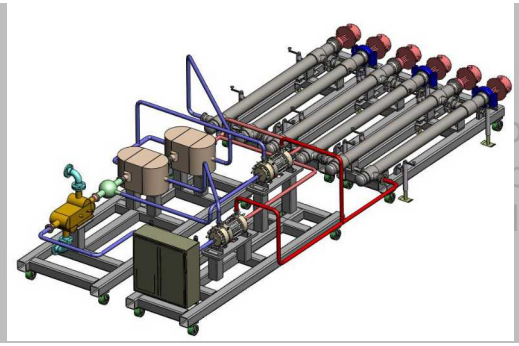

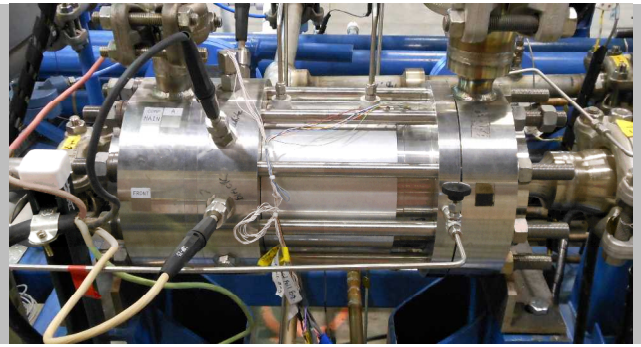

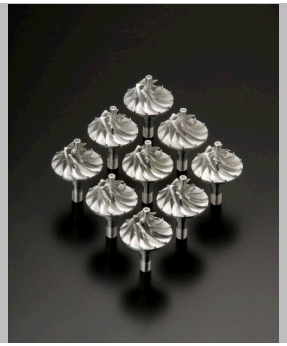

SUPERCRITICAL CO_2 BRAYTON CYCLE PROGRAM SUMMARY AND DEVELOPMENT ROADMAP

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6221 Advanced Nuclear Concepts
Nuclear Energy & Fuel Cycle Programs
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U.S. DEPARTMENT OF ENERGY | NNSA Nuclear National Security Administration

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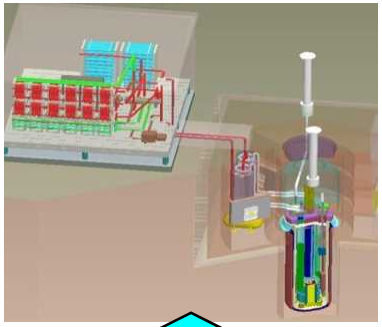
Advanced Energy Conversion



Nuclear

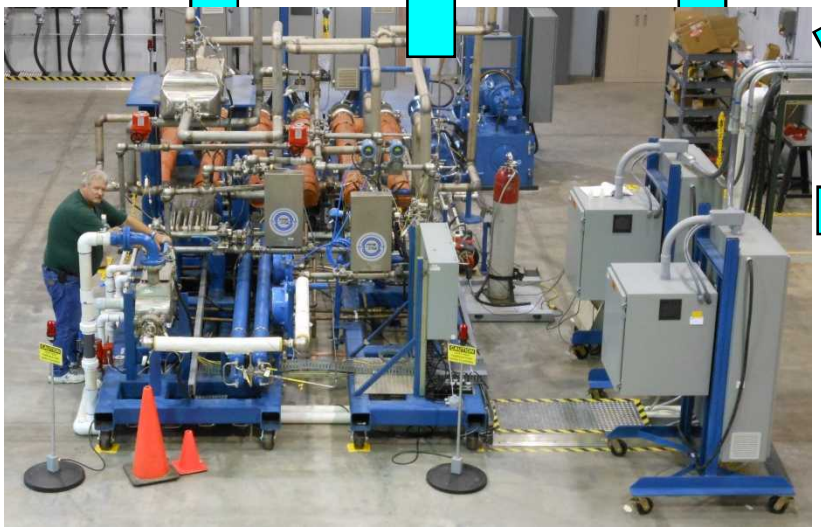
- **Using Supercritical Fluids**
- **Higher Conversion Efficiency**
- **1/10 of the Cost**
- **1/100 of the Plant Volume**

Fossil

Concentrated Solar

Geothermal

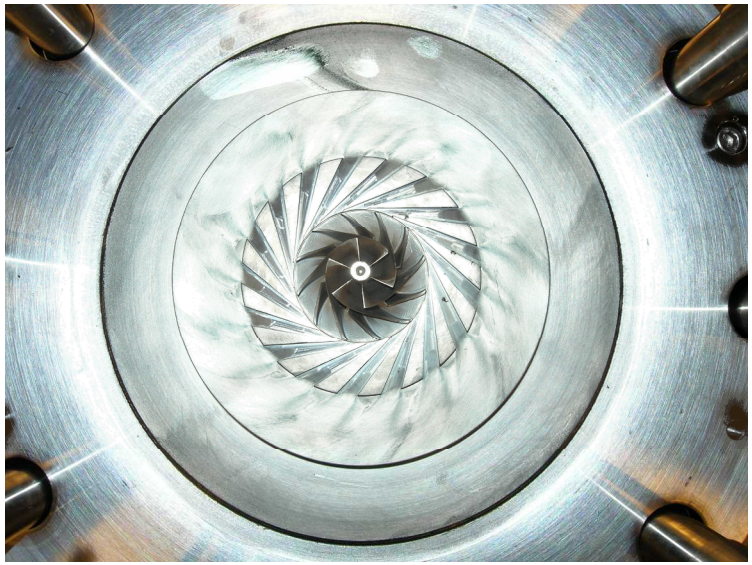
Turbomachinery

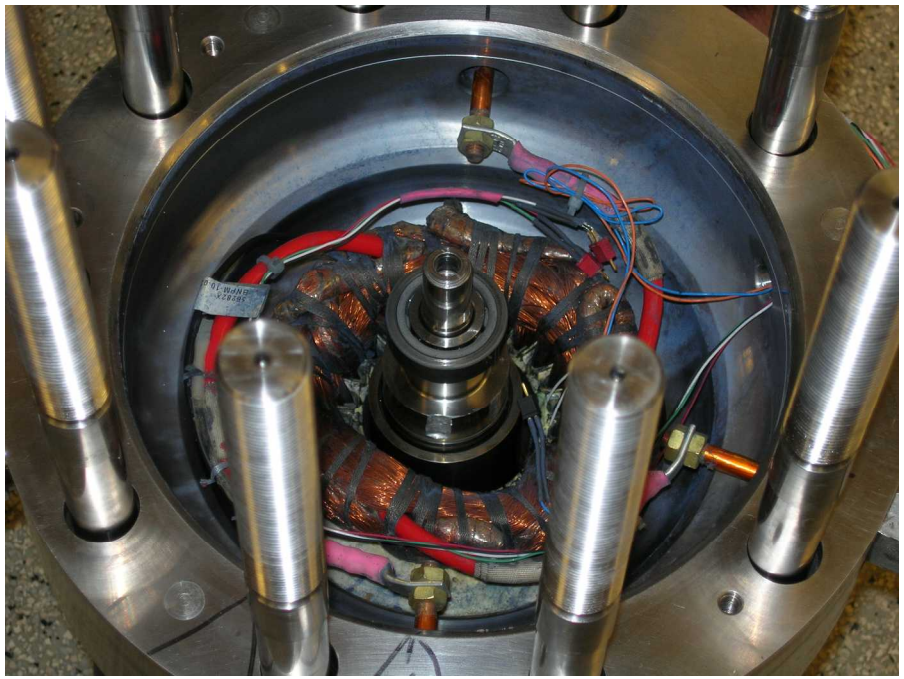


Industrial Heat

Goals of Presentation

- What is a Supercritical CO_2 Brayton Cycle?
- Why is it Important and How is it Used?
- DOE Advanced SMR R&D S-CO_2 Program Summary
  - Major Accomplishments
- Strategic Development Plan





What is a Supercritical CO_2 Brayton Cycle? How does it work?

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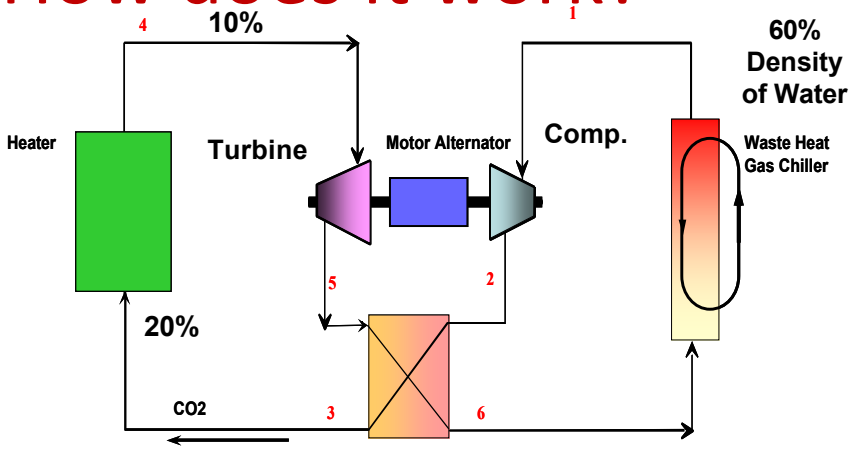
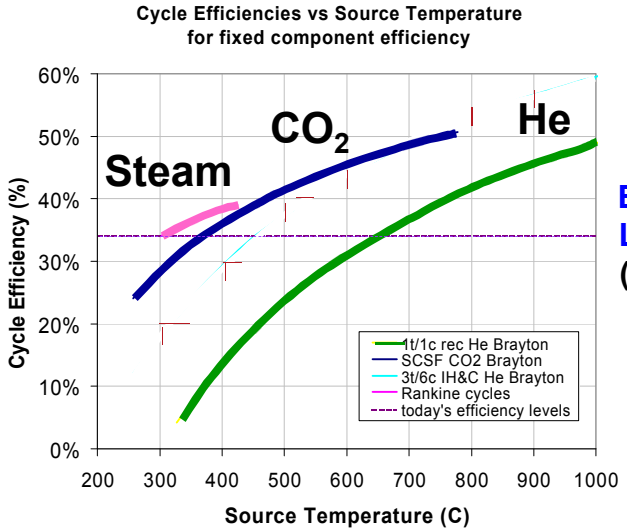
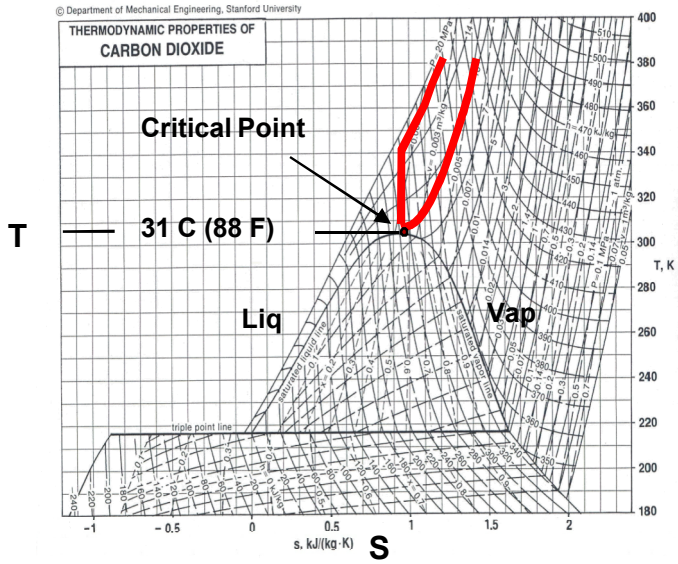


Liquid like Densities with CO_2
Very Small Systems,
High Efficiency due to Low Pumping Power

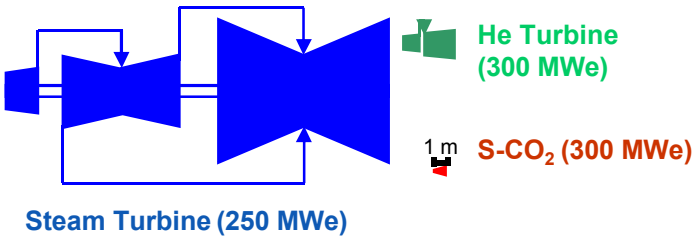


High Efficiency at Lower Temp (Due to Non-Ideal Gas Props)



Rejects Heat Above Critical Point
High Efficiency *Non-Ideal Gas*
Sufficiently High for Dry Cooling

Critical Point
88 F / 31 C
1070 psia / 7.3 MPa



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

Supercritical CO_2 Cycle Applicable to Most Thermal Sources

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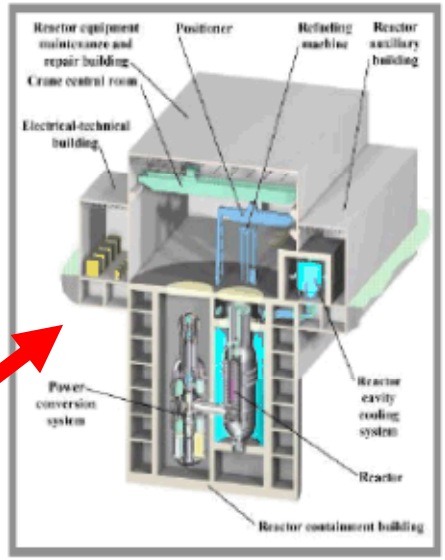
Solar

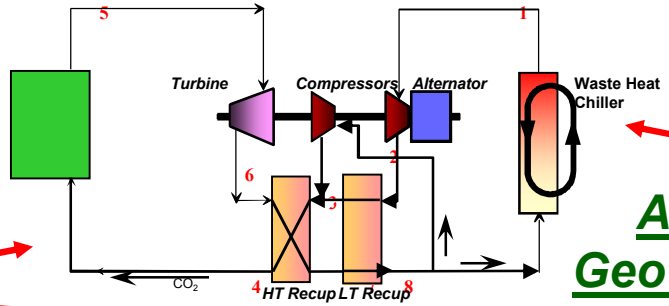
SunShot Power Cycle

Nuclear
(Gas, Sodium, Water)

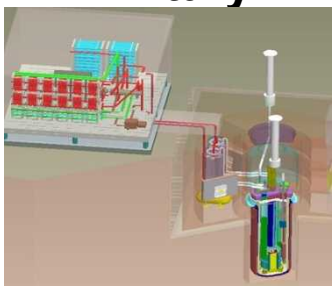
DOE-NE Advanced Reactors



Supercritical CO_2 Brayton Cycle

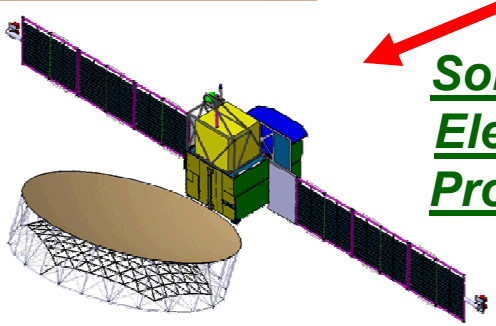


Military



CONUS Marine Mobile?

ARRA Geothermal



Solar Elec. Prop.

Fossil

Sequestration Ready

SNL/DOE Design Target for Proof-of-Principle Split-Flow Re-compression S-CO_2 Brayton Cycle

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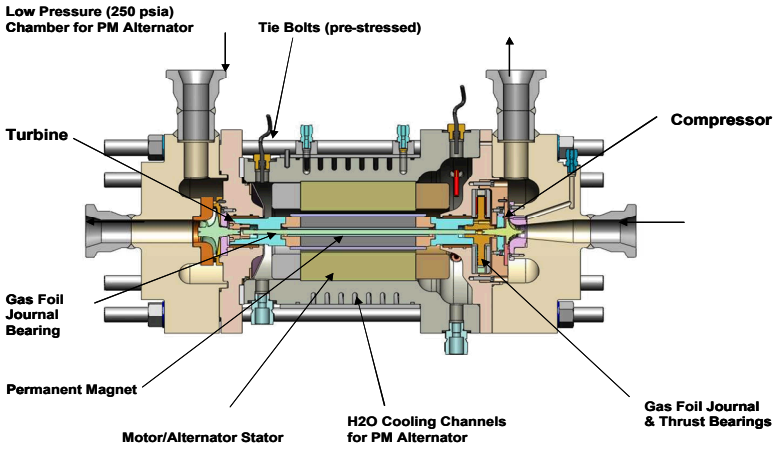
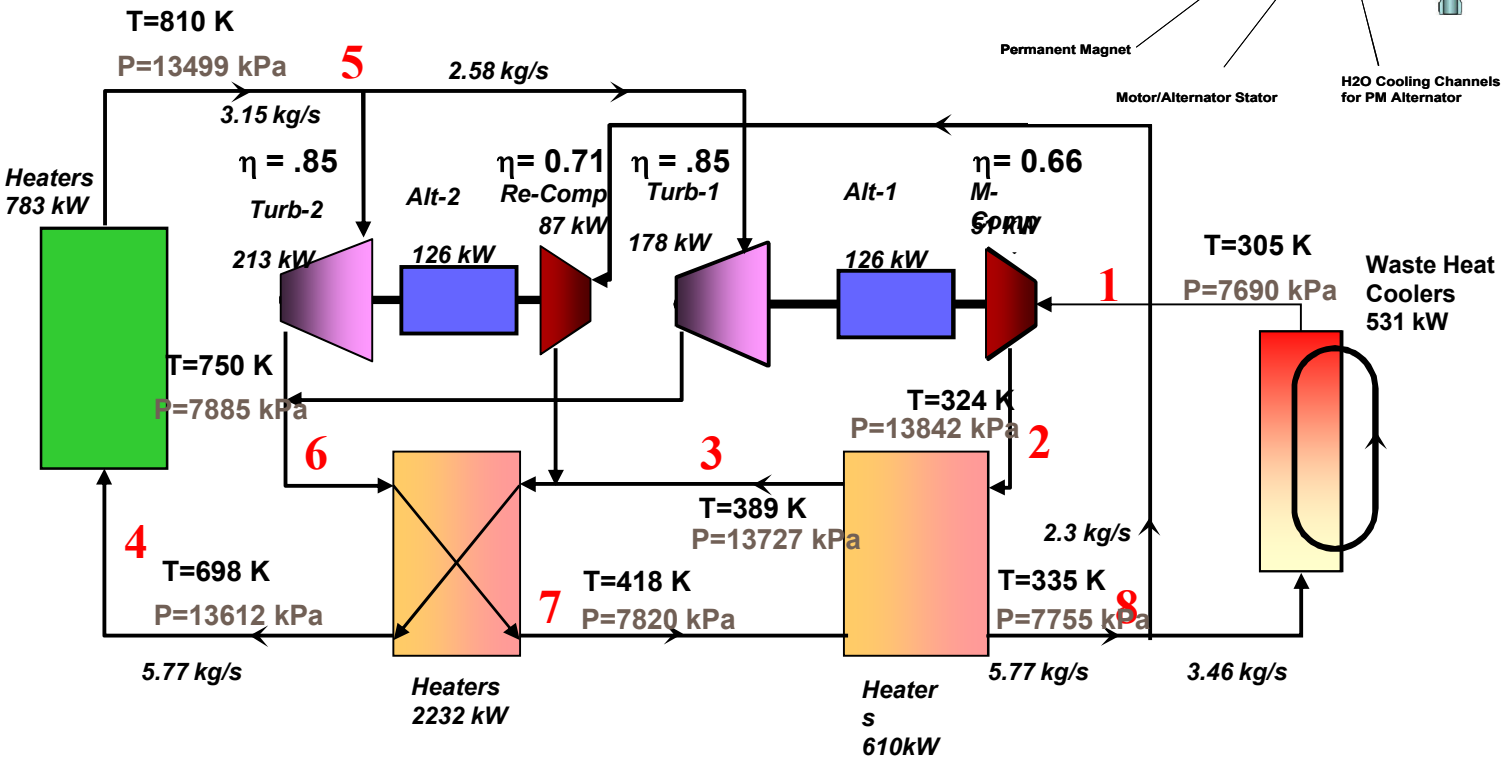
Modified Cycle to Enable Scaled Turbomachinery Development with Lower Risk

Dual Shafts, Lower Pressure Ratio





Key Technology
Turbo- Alternator Compressor Design

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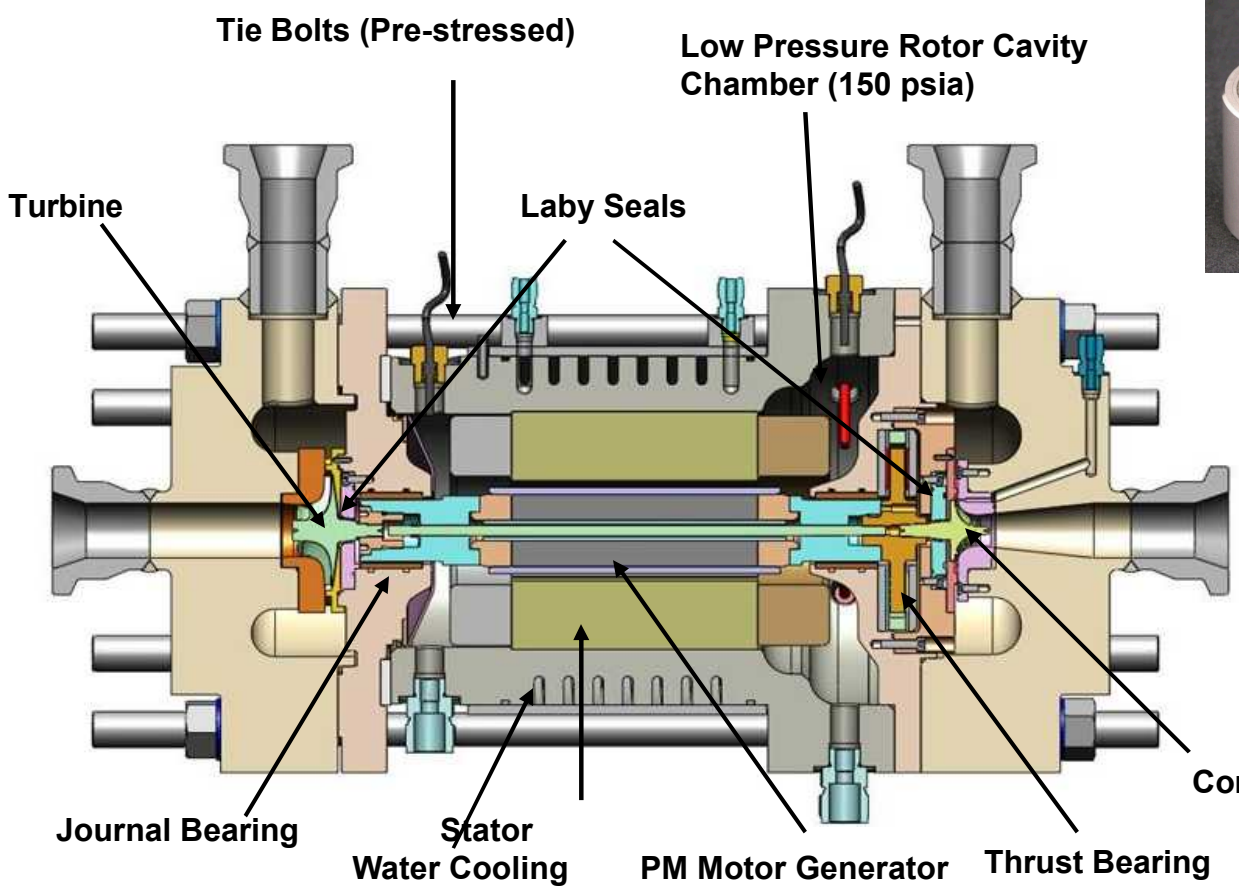
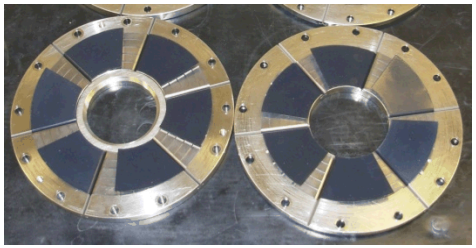
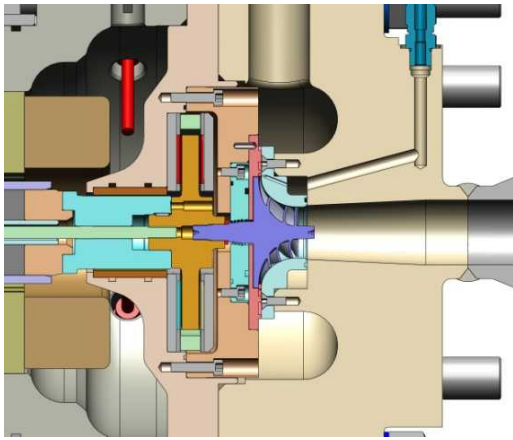


Capstone



Gas-Foil Bearings



International Patent Application is in Process for All major Features of this Design

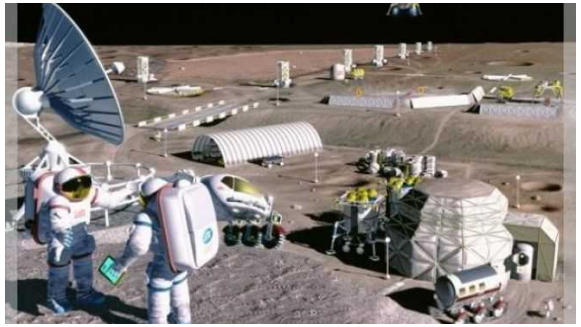
Design Details are Export Controlled - EAR

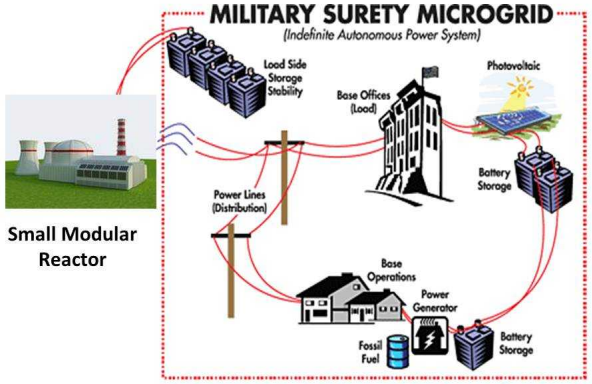
Status of the DOE Program

- **Sandia/DOE-NE S-CO_2 Program has Operating S-CO_2 Turbo-Machinery Test Loops**
  - Multiple Operational Loops and Flexible Configurations – Brayton Laboratory
  - These are currently among the leading S-CO_2 power production loops in the world
    - Other Loops are : (Japan TIT, Czech Republic, Echogen)
  - Power Production in multiple loop configurations
- **Multiple "Paying" Customers**
  - DOE-NE, Industry, Solar, Geo Thermal, Fossil
  - Over $13M Invested since 2006 (DOE-NE)
- **Advanced S-CO_2 Options Look Very Promising**
  - Condensing, Advanced Cycles, Natural Circulation, Dry Heat Rejection
- **Current Effort**
  - Demonstrate theoretical efficiency in the 1 MW_{th} Split Flow Loop
  - Demonstrate Fluid Mixtures, Other Supercritical Fluids, Advanced Cycles and Condensing Cycle for Dry Heat Rejection
  - Scale up Demonstration Program to 10 MWe for operation in 2014 with SunShot Program

DOE-NE R&D Goals

- Demonstration of the theoretical gross efficiency of the supercritical CO2 Brayton Cycle in FY13
- Operational characteristics of a same cycle (includes start-up, shut-down, transient response, load following and full operational model) expected mid-FY15
- Demonstration of commercial grade 10-MWe simple S-CO2 Brayton cycle with dry heat rejecti (50% DOE – 50% industry)
- Optimization of 10-MWe S-CO2 Brayton cycle in FY18. (Industry 50%, DOE- NE 10%, DOE-FE 20%, DOE-EERE 20%)
- After FY18 and beyond only industrial support.





Commercialization Goals

Industry Funded Projects

- Commercialization of 1-5 MWe S-CO2 Brayton Cycle in 2014 (applications: geothermal, solar, waste heat recovery)
- Commercialization of 5-15 MWe S-CO2 Brayton Cycle in 2016 (Power peaking systems)
- Optimized S-CO2 Brayton Cycle systems (cost and life cycle) in 2018 (Smart Secure Grid Systems)
- Commercialization of <300MWe optimized systems for (clean coal, SMRs, advanced power cycles)