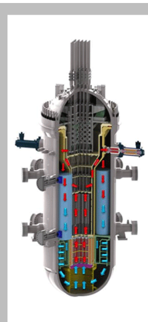
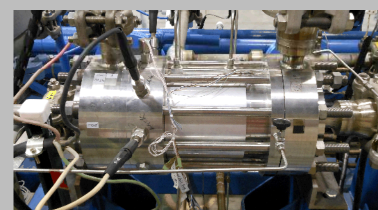
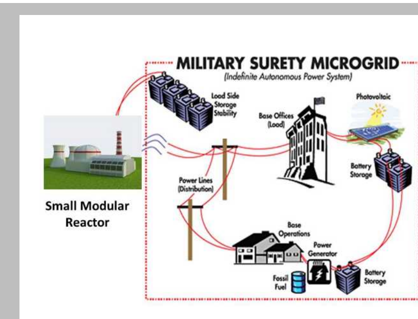
SAND2014-2189C

Exceptional service in the national interest

Sandia National Laboratories







Sandia Energy Conversion and SMR Programs

Gary Rochau, Advanced Nuclear Concepts, 6221

(505)845-7543, gerocha@sandia.gov

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Objective of Presentation

Overview of SNL Advanced Nuclear Concepts

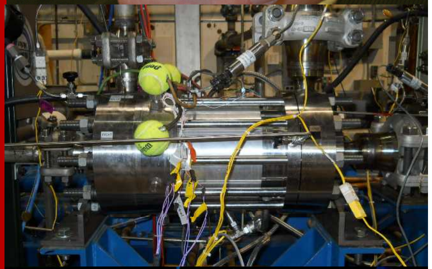
- Support of DOE-NE
- Support of NASA
- Advanced Energy Conversion Technology
- Radiation Effects Science
- Medical Isotope Production

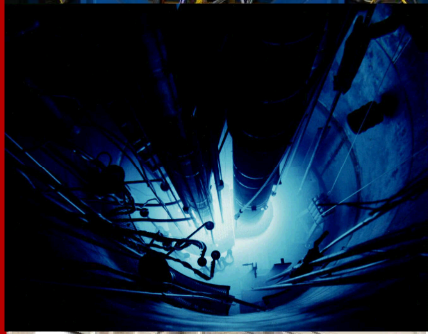
Support of Small Modular Reactors and Applications

- Demonstration of SMR safety and security
- Application to local grids
- Support of DoD Energy Security Objectives
- SMRs for Expeditionary Forces

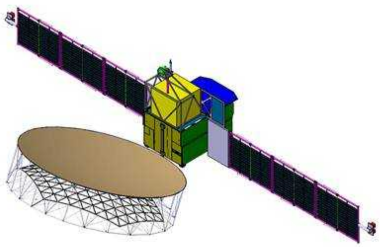
ADVANCED NUCLEAR CONCEPTS

6221 Programs



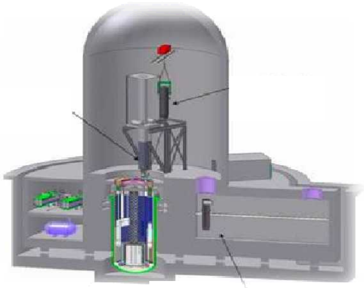


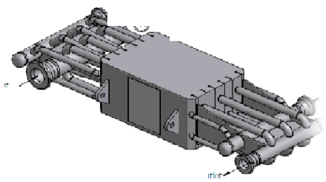
- DOE - NE
  - Energy Conversion Crosscut Management
  - Advanced Small Modular Reactors
    - Brayton Cycle Development
    - Advanced PRA
    - MELCOR/CONTAIN Integration
  - Advanced Reactors
    - Advanced Heat Exchangers
  - Safeguards and Security Evaluation for Advanced Reactors
  - Integrated Safety, Operations, Security and Safeguards
  - Transient Fuel Testing
  - Advanced high temperature hydrogen production
- Space Nuclear Power
  - Fission Surface Power Program
    - Moon Base Reactor
    - Simulator Development
  - Nuclear Thermal Propulsion
    - Reactor calculations/criticality
  - Solar Electric Propulsion
    - Northrop Grumman CRADA
    - Advanced Power Systems for Space
- Brayton Cycle Commercialization
  - R&D for Recuperated Closed Brayton Cycle
  - SunShot 10 MWe Demonstration
  - GE DReSCO Demonstration
  - Advance Waste Heat Recovery
- DoD Energy Security
  - SMR applications for CONUS Bases
  - Secure/Smart Grids for CONUS, OCONUS, FOB, and Expeditionary Power
  - “Hot Rock” reactor of FOB and Expeditionary Power
- Production of Medical Isotopes
  - Design of reactors with low enriched fuels
  - Design of isotope recovery processes
  - Technology Transfer of historical processes

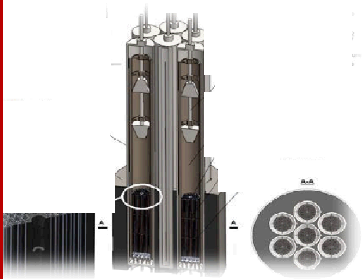


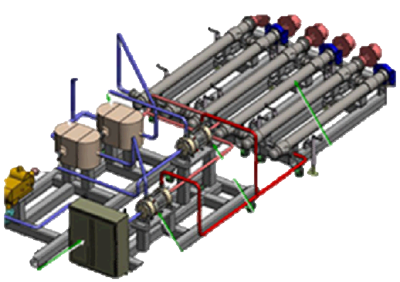
ADVANCED NUCLEAR CONCEPTS

6221 FACILITIES









6221 is responsible for 6 labs in Tech Area III and Tech Area V

6580/209 – Radiation Effects Diagnostic Development and Production(Light Lab)
Development of radiation diagnostics; calorimeters, detectors, and experiment packages for experiments on ACRR, Z-Machine, WSMR/Spur, and LANL. Supported by Org 1380 for Radiation Effects Science. Work focuses primarily on diagnostics for experiments and cabling. Full ILMS documentation and Operating Envelope defined.

6585/1404 – Nuclear Systems Design Laboratory(Light Lab)
Laboratory used for mechanical design activities. Two offices currently in use. Capabilities include SolidWorks Work Stations and Drawing plotting equipment. Specialty Software includes CEASAR, MCNPX, ORIGIN, and CINDER.

6585/2501 – Wet Chemistry Laboratory (Light Lab)
Development of material interaction and corrosion studies for S-CO2, arsenic water treatment, and radiological barrier development.

6585/2503 – Transient Fuel Testing Technology Laboratory(Light Lab)

Development of advanced hardware and diagnostics for transient reactor fuel testing in ACRR. High pressure equipment to develop strain gauge techniques and advanced optical techniques to make real time measurement of fuel cladding strain to failure in pulsed ACRR neutron flux.

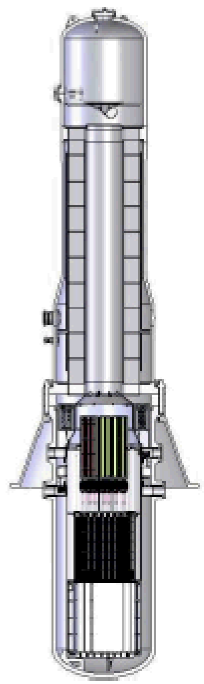
6585/2504 – SMR Simulator Laboratory(Light Lab)

Development of Small Modular Reactor system models to support system integration for Department of Defense installations and Advanced Fuel Burnup calculations. Currently houses 2 servers for computational modeling of SMRs supporting DoD bases and the buildup of isotopes in high burn up fuels. Future planned for a severe nuclear accident simulator

6630/7,12N,12,12S, 13, 14 – Nuclear Systems Engineering Lab(NESL)/Brayton Cycle Laboratory
Operating closed Brayton Cycle demonstrating operation of the cycle with supercritical fluids working at high pressures and temperatures. Current equipment includes Atmospheric Pressure Closed Brayton Cycle, S-CO2 compressor system, Split Flow Supercritical CO2 Brayton Cycle, and Mechanical Modification & Development Lab. Development of reactor simulator in support of the NASA Fission Surface Power Program. Computer-based simulators are interfaced to hardware to test control functions of RPCSim prior to shipment to NASA Huntsville.

First Generation US Small Modular Reactors

- Babcock & Wilcox
  - mPower
  - 180 MWe
- NuScale Power, Inc.
  - NuScale
  - 45 MWe
- Westinghouse Nuclear
  - 225 MWe
- Holtec International
  - 160 MWe
- Common Features
  - Steam Generators inside pressure vessel
  - Light water moderation
  - Passively safe
  - All cores underground



mPower

NuScale

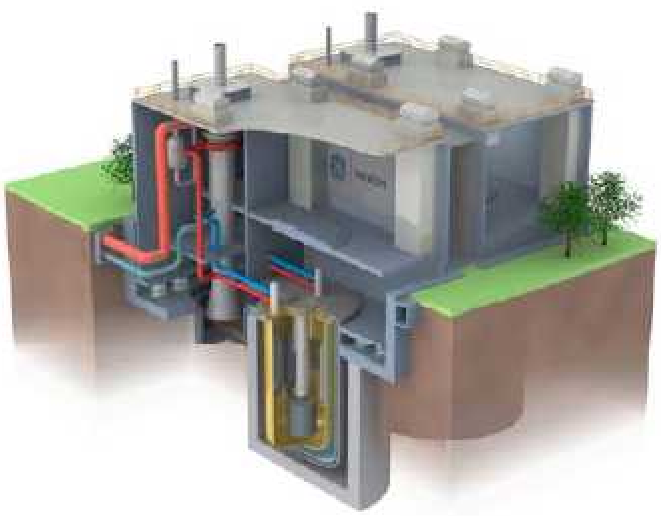
Westinghouse

Holtec

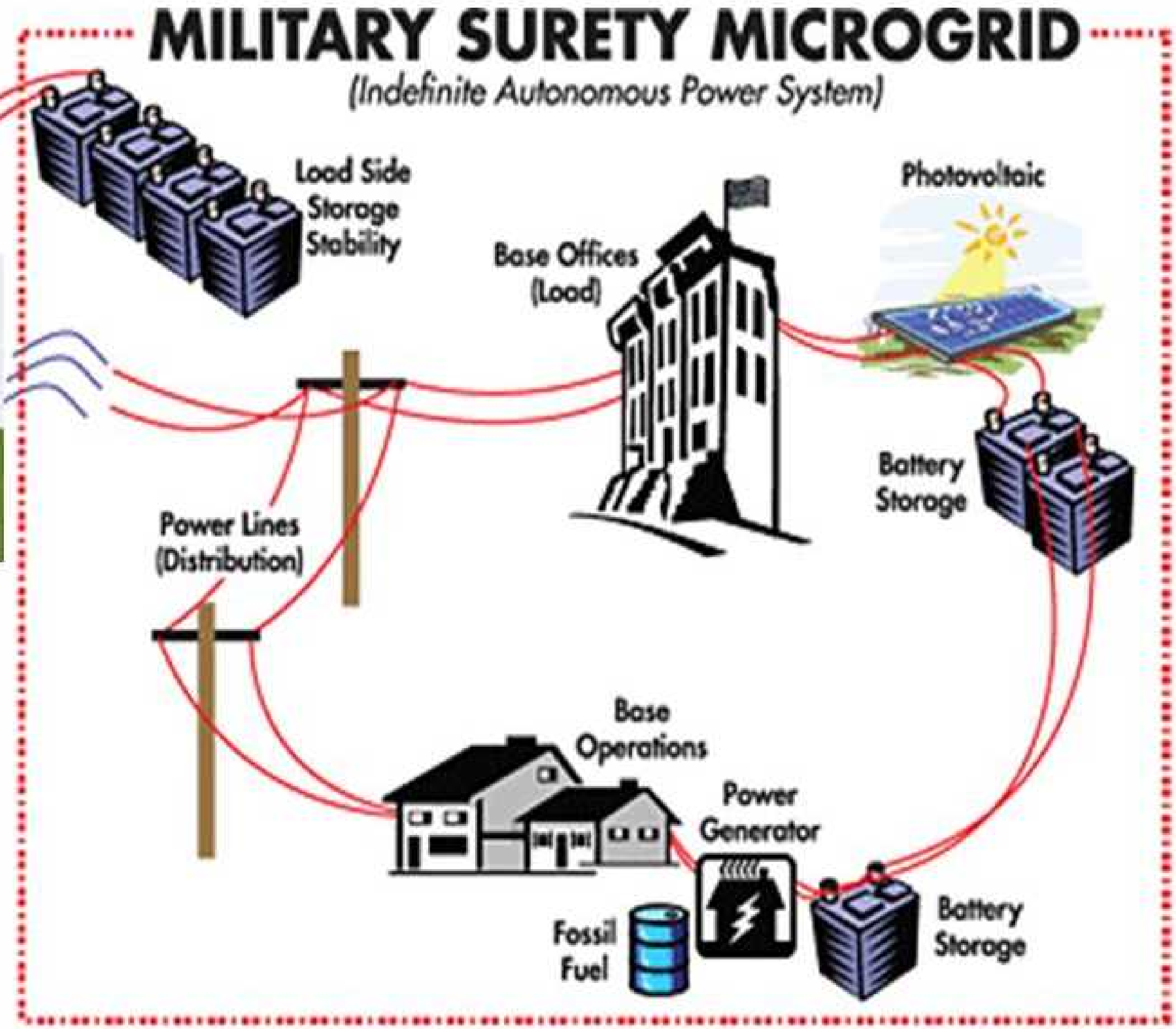
Advanced US SMR Designs

- **Brookhaven Technology Group**
  - Global Energy Module (GEM50)
  - 10 MWe
- **General Electric**
  - Power Reactor Inherently Safe Module (PRISM)
  - 311 MWe
- **Hyperion Power Generation**
  - Hyperion Reactor
  - 30 MWe
- **TerraPower**
  - Traveling Wave Reactor (TWR)
  - 500-1200 MWe
- **Westinghouse - Toshiba**
  - Toshiba 4S (Super Safe, Small and Simple)
  - 10 MWe

- GE Prism and Toshiba 4S most mature
- TerraPower legitimized by Gates
- Molten Salt and High Temperature Gas Reactors entering the field
- Advanced designs anticipate advanced fuel cycles and industrial applications



Small Modular Reactor



Can SMRs Benefit Military Surety Microgrids?

- SMRs have the lowest carbon footprint of any power provider.
- SMRs should have a capacity factor equal to or greater to their big brothers at >90%
- SMRs can provide energy independence from the commercial grid to DoD bases and affected community
- SMRs have the potential to generate electricity without the use of fresh water for heat rejection.
- SMRs can provide process heat to support:
  - Water desalination
  - Fuel production
  - Production of equipment currently

Questions that need answers

- Will DoD installations Own, Operate, or Secure SMRS?
  - DoD installations do not expect to Own, Operate, or Secure SMRS
  - Past experience has indicated that other than Navy propulsion, nuclear power operations are better handled by others.
- Who will regulate reactors supplying power to DoD facilities?
  - The U.S. Regulatory Commission
- Who will own the legacy of a reactor supplying DoD facilities?
  - Not the DoD. It will follow under the current Waste Confidence Rule.
  - Waste fund will be part of operational cost
  - Spent nuclear fuel will be treated as civilian fuel.
  - Decommissioning will be funded by operating entity generate fund.
- Where will such reactors be located?
  - Assumed to be very near to DoD sites and possibly on DoD leased land.

Questions that need answers

- What Commercial/Base relationships are possible?
- What current conditions/requirements need to be changed?
  - Emergency planning zones push SMRs too far away to secure transmission.
  - Commercial grid failure causes “station blackout” and reactor trip.
  - SMRs may not be able to load follow
- What DoD requirements are unique for SMRs?
  - What does secure power mean?
  - Is energy independence desirable?
  - Water usage, fuel production, etc.?
- What size SMR is the right size? How does it integrate with the community/utility?

Current Sandia Activities Advanced SMR R&D DOE-NE

- Management and Integration of SMR capabilities to DOE-NE Program
- Demonstration of Supercritical CO2 Brayton cycle
- Evaluate the potential to reduce requirements for operations, security staffing, and emergency preparedness
- Evaluation of Safeguards and Security requirements for first generation and advanced SMRs
- Advanced Probabilistic Risk Assessment Methods for SMR operations, security, and safeguards

Recent New Sandia Activities Advanced SMR R&D DOE-NE

- MELCOR/CONTAIN Liquid Metal Reactor Severe Accident Safety code Integration
- Compact Heat Exchanger Development for Supercritical CO2
- Development of Advanced Heat Exchangers for Power Systems
- Extension of Aerosol Modules during severe accidents to 1st generation iPWR SMRs – Collaboration with EPRI
- Extension of Severe Accident Models to submerged containments with natural circulation – Collaboration with NuScale

Current Sandia Activities Proliferation Assessment DOE-NA

- Assessment of the proliferation and security risks for first generation US SMRs exported to foreign countries
- Vulnerability Assessment for Advanced Small Modular Reactors at the Conceptual Design Stage – Joint with DOE-NE

Successfully Completed Recompression Closed Brayton Cycle (RCBC)Test Article (TA)

- 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
- Developing maintenance procedures

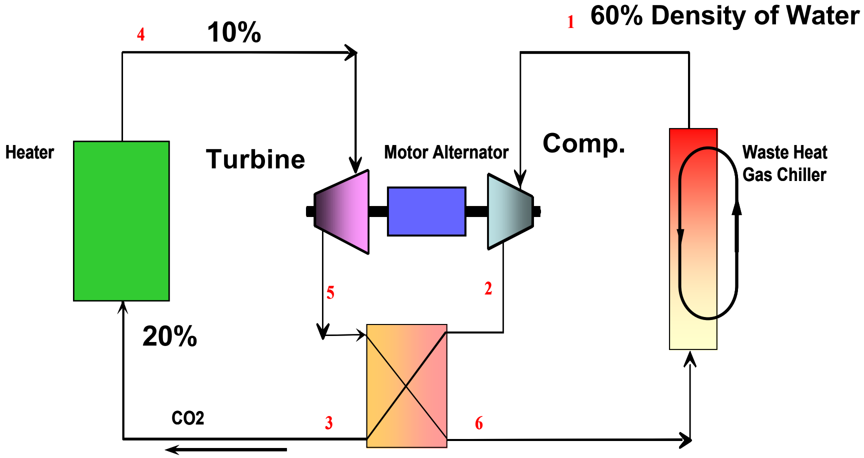
<u>TA Description:</u>

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

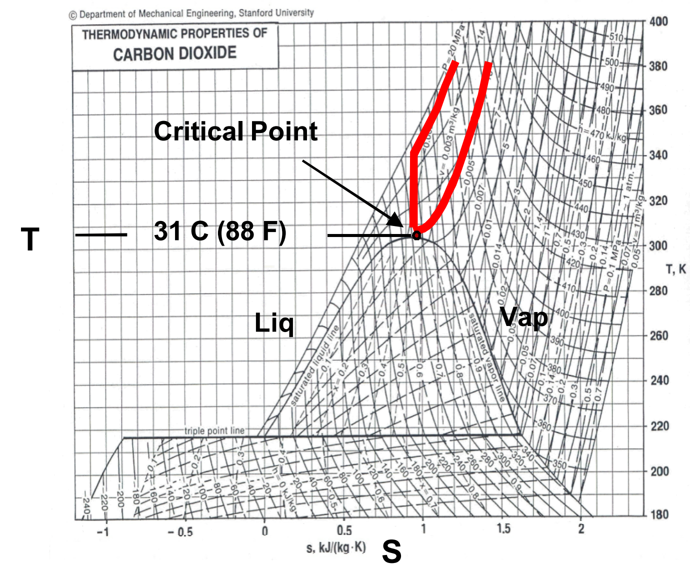
Load Bank – 0.75 MWe
Gas Compressor to scavenge TAC gas
Inventory Control
Turbine Bypass(Remote controlled)
ASME B31.1 Coded Pipe, 6 Kg/s flow rate
Engineered Safety Controlling Hazards
Remotely Operated

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

Sandia National Laboratories



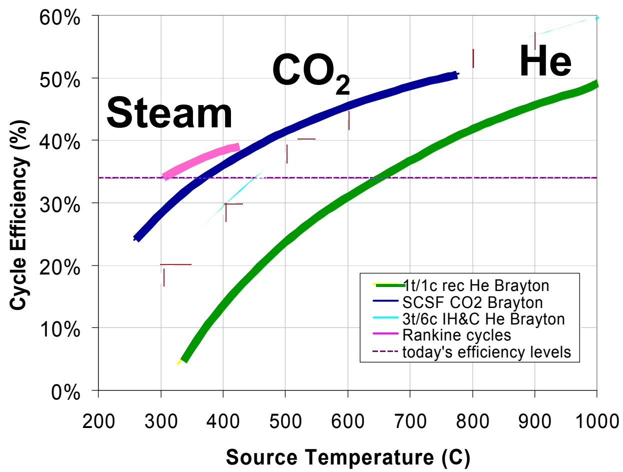
Liquid like Densities with CO_2
Very Small Systems,
High Efficiency due to Low Pumping Power

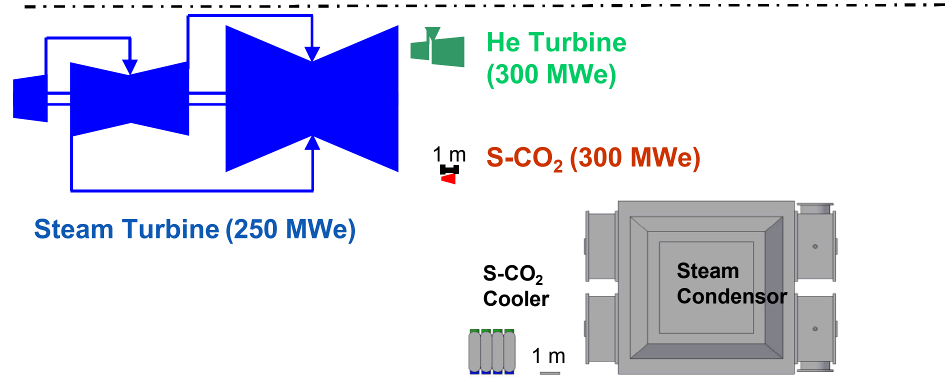


Rejects Heat Above Critical Point
High Efficiency ***Non-Ideal Gas***
Sufficiently High for Dry Cooling

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

Cycle Efficiencies vs Source Temperature for fixed component efficiency





Supercritical CO_2 Cycle Applicable to Most Thermal Heat Sources

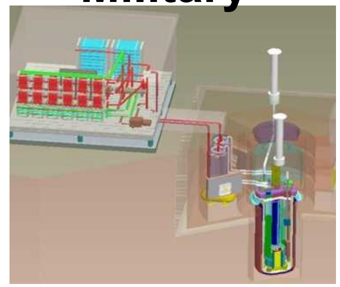
Sandia National Laboratories

Solar

CSP Solar Tower

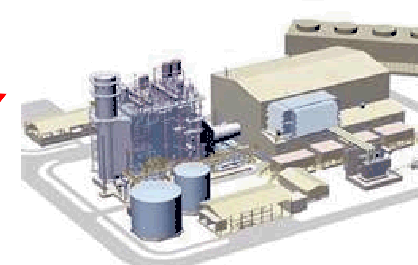
Fix Base & Marine

Military

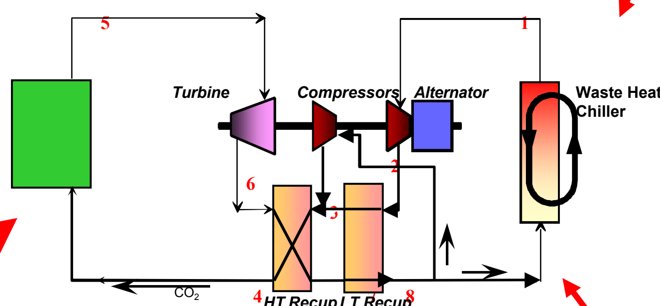


ARRA Geothermal

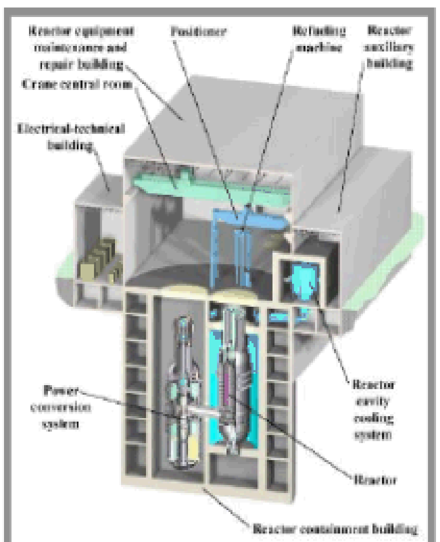
Waste Heat
Bottoming Cycle to a Gas Turbine



Recompression Supercritical CO_2 Brayton Cycle

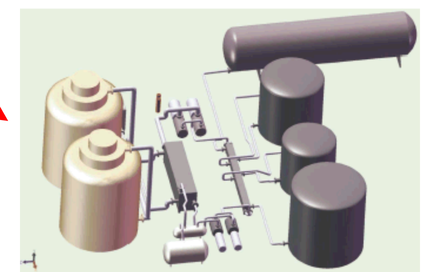


Nuclear
(Gas, Sodium, Water)



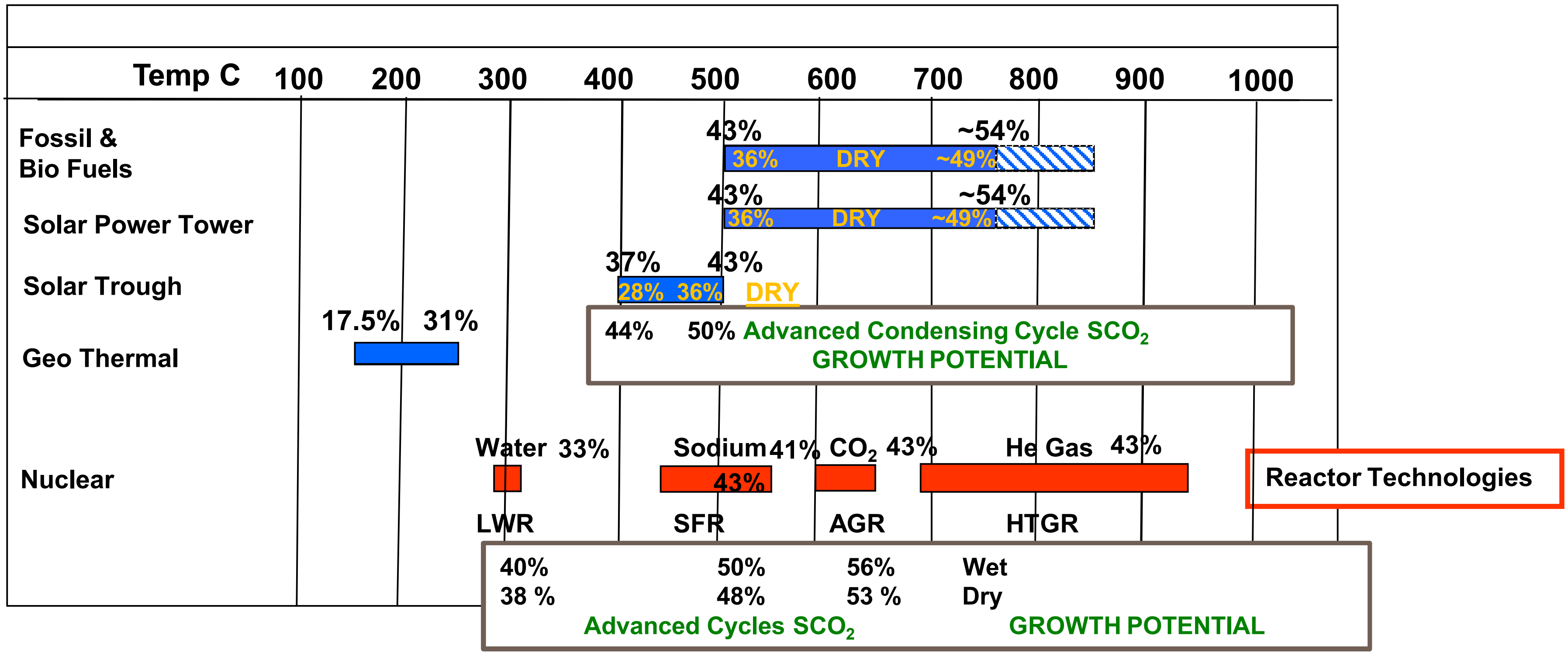
DOE-NE Gen IV

Carbon Capture & Sequestration
CCS Fossil



Energy Storage

Heat Source Operating Temperature Range & SCO_2 Power Conversion Efficiency for Various Heat Sources



S-CO_2 Power Conversion Operating Temperatures Matches Can be Applied to All Heat Sources
Optimum Design Requires Different Approaches for Each Heat Source
Supercritical Fluid Technology has Untapped Growth Potential

Assumptions (Turbomachinery Eff (85%/87%/90% : MC/RC/T), 5 K Approach T, 5% dp/p losses, Hotel Losses Not In Included, Dry Cooling at 120 F)

Future SMR Activities

Energy Conversion

- Extend Brayton cycle to power generation levels
- Identify the first markets of the Brayton cycle to initiate commercialization
- Harness the flexibility of supercritical fluids to multiple applications
- Eliminate the need for water to reject heat

Reactor Safety and Security

- Demonstrate scalability of natural convection
- Demonstrate the very low probability of off site release during severe accident
- Eliminate the need to generate steam
- Reduce staffing levels through integration of safety, operations, security and safeguards functions