Sandia National Laboratories

Energy, Climate &
Infrastructure Security

Nuclear Energy Systems Laboratory (NESL) Brayton Laboratory

The vast majority of electricity produced around the world uses a general cycle that pressurizes a fluid, heats it so that it has a lot of expansion capability, then blows it through a turbine that operates a generator. The low pressure fluid exits the turbine, is condensed by removing heat, and pressurized again and reused in this cycle.

The most common cycle boils pressurized water to create steam, which is then expanded through the turbine. This cycle efficiency is around 33%, which means that 33% of the thermal energy delivered to the fluid is actually converted into electricity.

The Goal:

Raise electricity production efficiency from the current 33% up to 50% using a cost effective system.


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Why It's Important:

A 1% improvement in efficiency reduces greenhouse gas emissions by an estimated 2.9%. Increasing efficiency to 50% reduces emissions by 34%. Consumer costs will also decline as efficiency improves and fewer natural resources are consumed.

The Approach:

Use thermodynamic laws to determine the best fluid and conditions for each part of the cycle: pressurization, heating, expanding through the turbine, and heat transfer in heat exchangers.

What Thermodynamics Tells Us About Using Steam:

The major drawback to using the traditional steam cycle is that most of the heat that remains in the steam after it leaves the turbine must be rejected from the fluid to turn it back into liquid water that can be recompressed and sent through the cycle again. This heat energy cannot be transferred back into the liquid leaving the compressor because both flows are at very nearly the same temperature. The rejected heat represents a large fraction of the heat that is put into the system at the heater, which results in a significant hit to cycle efficiency.

What Thermodynamics Tells Us About Using S-CO2:

Most of the heat that remains in the S-CO2 after it leaves the turbine is recuperated within the system. That is, most of the heat is put back into the cold fluid exiting the compressor before it enters the heater. This is because the S-CO2 does not have to undergo a constant temperature phase change to reject heat. A useful temperature difference exists between the fluid exiting the turbine and the fluid exiting the compressor. Only a small amount of heat needs to be rejected from the cycle to get the S-CO2 at the right density to recompress it.

Research and Development at Sandia National Labs

Sandia took the lead in investigating this cycle using internal R&D funds in 2007. Initial investigations focused on the stability of S-CO2 as a working fluid very near the fluid's critical point – a thermodynamic state in which fluid properties vary dramatically. With early positive results, the DOE funded development of a more extensive test article. The current testing configuration consists of two Turbine-Alternator-Compressors (TAC's) designed to produce 125 kW of electricity each, a bank of heaters with 780 kW capacity, two recuperators to transfer heat from the high temperature flow exiting the turbine to the low temperature flow exiting the compressors, and a heat rejection heat exchanger.

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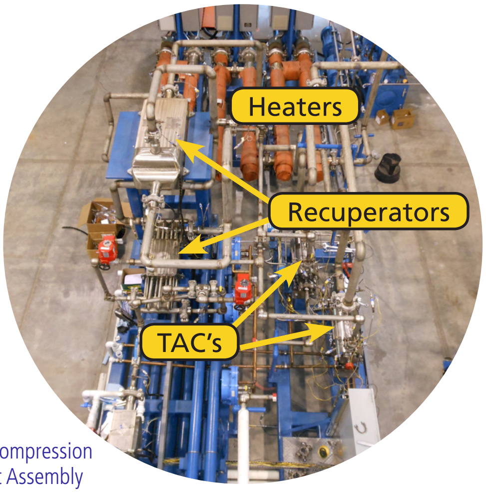
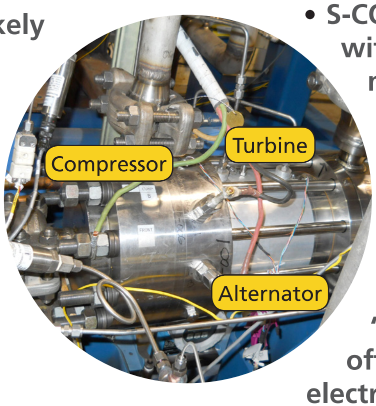


Recompression Test Assembly

While significant progress has been achieved to date in understanding how to start the system and various operational dynamics, significant and extensive R&D remains to be completed to determine:

- The optimum configuration for each of the numerous applications.
- The best way to take each configuration from a cold start to full power, and then shutdown.
- The interaction of the various system components during transients.
- Areas of efficiency losses and methods to minimize these losses.
- The reliability and likely failure modes of various components and materials.
- Development and validation of the various computer simulations needed for full scale power generation plants.



General Benefits of Using S-CO2

S-CO2 power conversion technology offers a number of benefits over competing cycles. These include:

- S-CO2 is a very benign fluid. Instead of a fire hazard, it will actually help to suppress fires should an accidental pipe break occur. For this reason, the cycle can be used to generate power in areas where minimizing fire hazards is essential.
- The fluid remains in a relatively dense state, therefore components are very small compared with traditional steam cycles. This reduces material costs, reduces facility size, and enables applications that require significant power in a small volume.
- The thermodynamic cycle can generate power over a wide range of commonly available heating temperatures. This is because the critical temperature of CO2 is a very low 87°F, and theoretically, any heat source above this temperature can sustain an S-CO2 power generation cycle. Other common cycle fluids – most notably water – require significantly higher temperatures.
- S-CO2 is compatible with common building materials, therefore reducing the need for costly R&D for specialized materials and components.
- Through a heat rejection process called 'dry cooling,' the cycle offers an economical electricity-generation solution in areas that can't provide cooling water. The high solar heat availability in the desert, coupled with dry cooling, make the S-CO2 cycle ideal for Concentrated Solar Power applications.

Interesting Facts

- The thermodynamics that describes the compression, heating, and expansion of the S-CO2 is actually the same as for a jet engine. The difference is that the S-CO2 closed loop cycle takes the turbine exhaust and reuses it.
- The first closed Brayton cycle power plant was built in 1939 in Germany. The power plant used air instead of S-CO2. Germany built a number of these power plants, often with waste heat used to heat homes in town (cogeneration).
- Sandia National Labs first produced more electricity than it consumed in the TAC in March 2010, on a single TAC loop.
- Sandia National Labs has the first and only known closedloop recompression S-CO2 Brayton cycle in the world, making it a unique and valuable testing system.
- The S-CO2 TAC and related system is so small that it has been considered for several space-based power generation applications, including powering an ion-drive space tug to move orbiting debris away from satellites, and for auxiliary power generation for manned missions to Mars.

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