INL/CON-24-80456-Revision-0

Alternatives to MARVEL Power Conversion -- Comparison of Stirling Engine Thermal Efficiency and Design to Other Power Conversion Cycles

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Alternatives to MARVEL Power Conversion -- Comparison of Stirling Engine Thermal Efficiency and Design to Other Power Conversion Cycles

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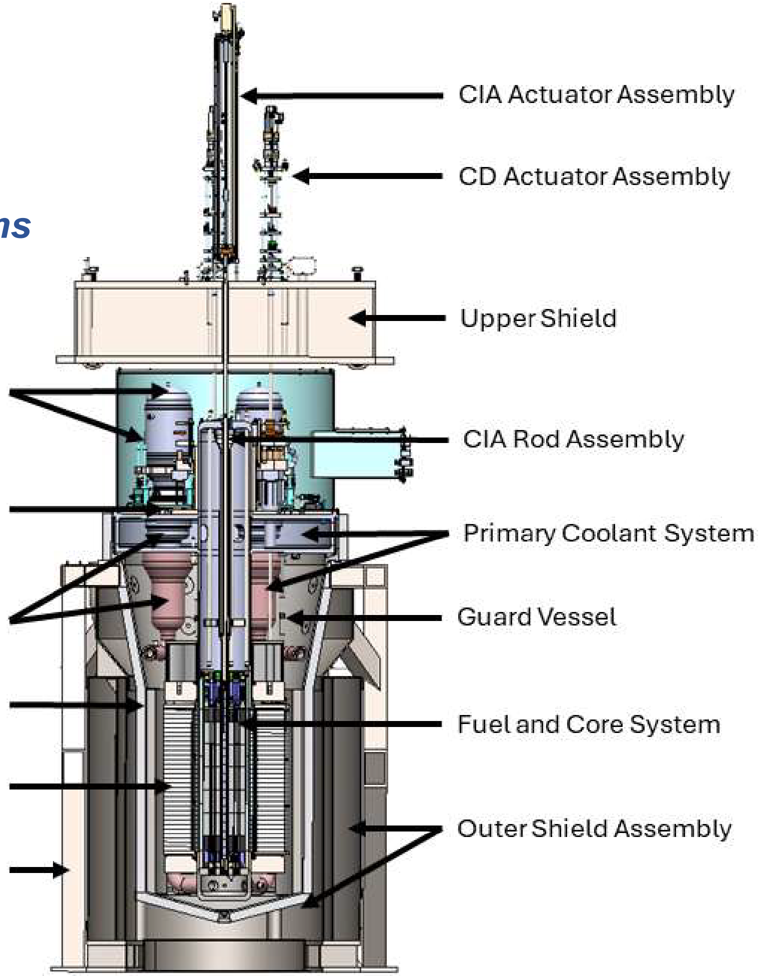
NE-5 Microreactor Program

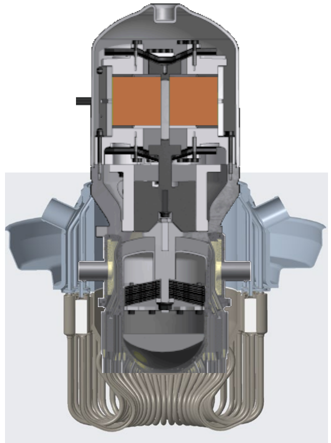
American Nuclear Society

Background and Purpose

- MARVEL - 85 kW_{th} microreactor to be constructed at INL to demonstrate heat applications including power production
- Stirling engines are MARVEL’s planned method of power production, with several limitations:
  - Corrosion from eGaInSn secondary coolant
  - Radiation fields limit Stirling engine life
  - Thermal stresses imposed on upper distribution plenum by ΔT imposed by cooling water limits
- Purpose - analyze alternative power cycles for comparison to:
  - Identify configurations that may address limitations and improve operational flexibility
  - Compare thermal efficiency for microreactor developers and end-users

MARVEL systems/subsystems





Stirling Engine:

$\eta_{th\ in\ MARVEL}$ = ~23.5%

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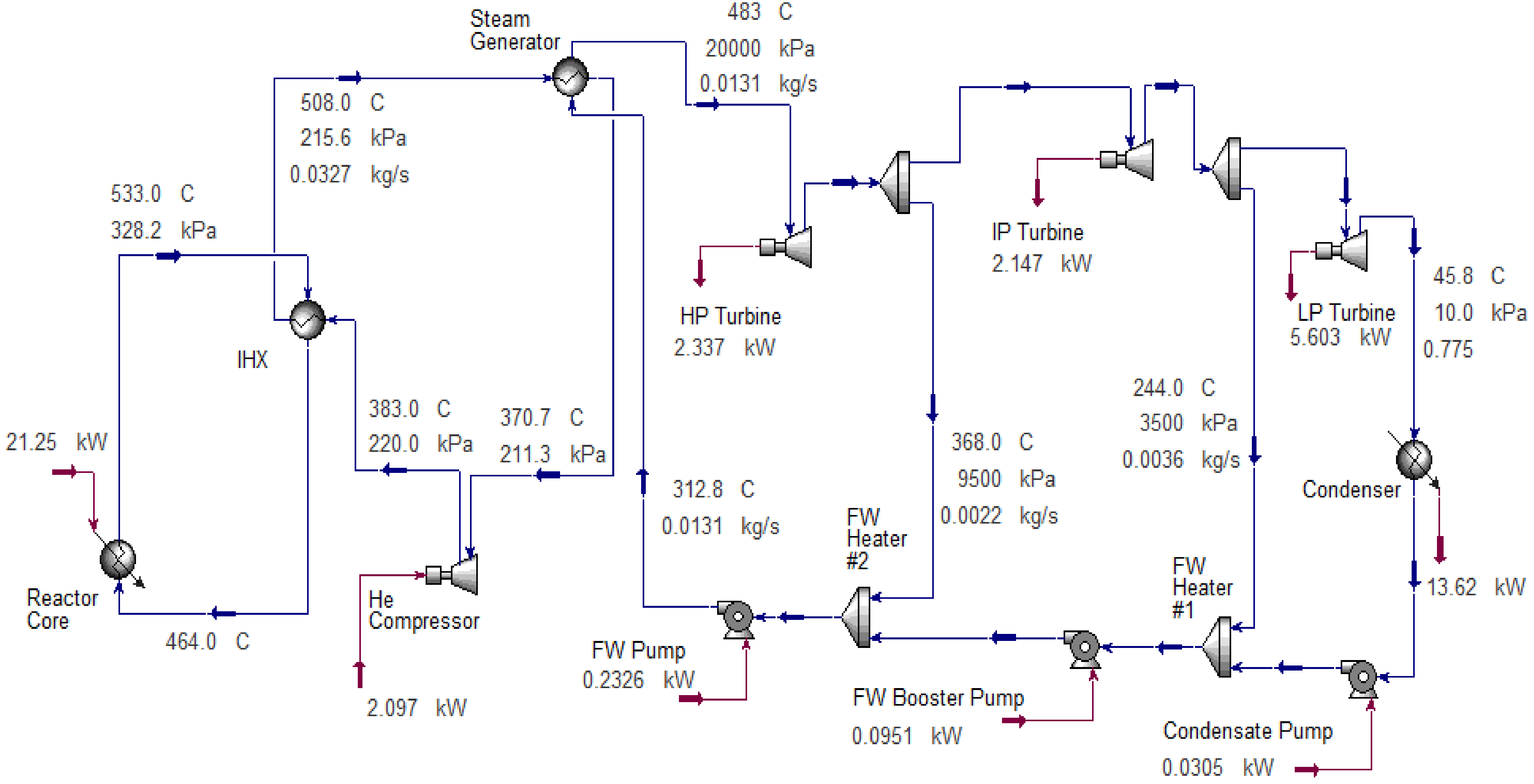
Overview of models

- Power conversion models developed in Aspen HYSYS 12.1(Superheated Rankine, Open and Closed Brayton Cycles, Super-critical CO_2 Cycle)
- Assumptions
  - Model input (reactor core and primary coolant system) based on MARVEL 90% final design and one of four identical loops (total output = 4X one loop's output by symmetry)
  - Secondary coolant system – Stirling engines with natural circulation using eGaInSn secondary coolant replaced by an intermediate helium loop consistent with NRC principal design criterion (PDC) 78 in all models
- Parameters – reasonably achievable with available technology
  - Minimum heat exchanger approach temperature = 25°C.
  - Minimum differential stream temperature for heat exchangers = 25°C.
  - Minimum differential stream temperature for recuperators = 10°C.
  - Pressure drops across heat exchangers = 2%.
  - Adiabatic compressor efficiency = 85%.
  - Adiabatic pump efficiency = 85%.
  - Adiabatic turbine efficiency = 90% .
  - Intermediate Loop Pressure set to approximately 220 kPa to minimize the effects of a tube leak on core neutronics (due to coolant voiding in the fuel).

Superheated Rankine Cycle



- Observations:
  - Widely used, mature technology
  - Most common cycle among MRP developers
  - Improves thermal efficiency compared to Stirling engines

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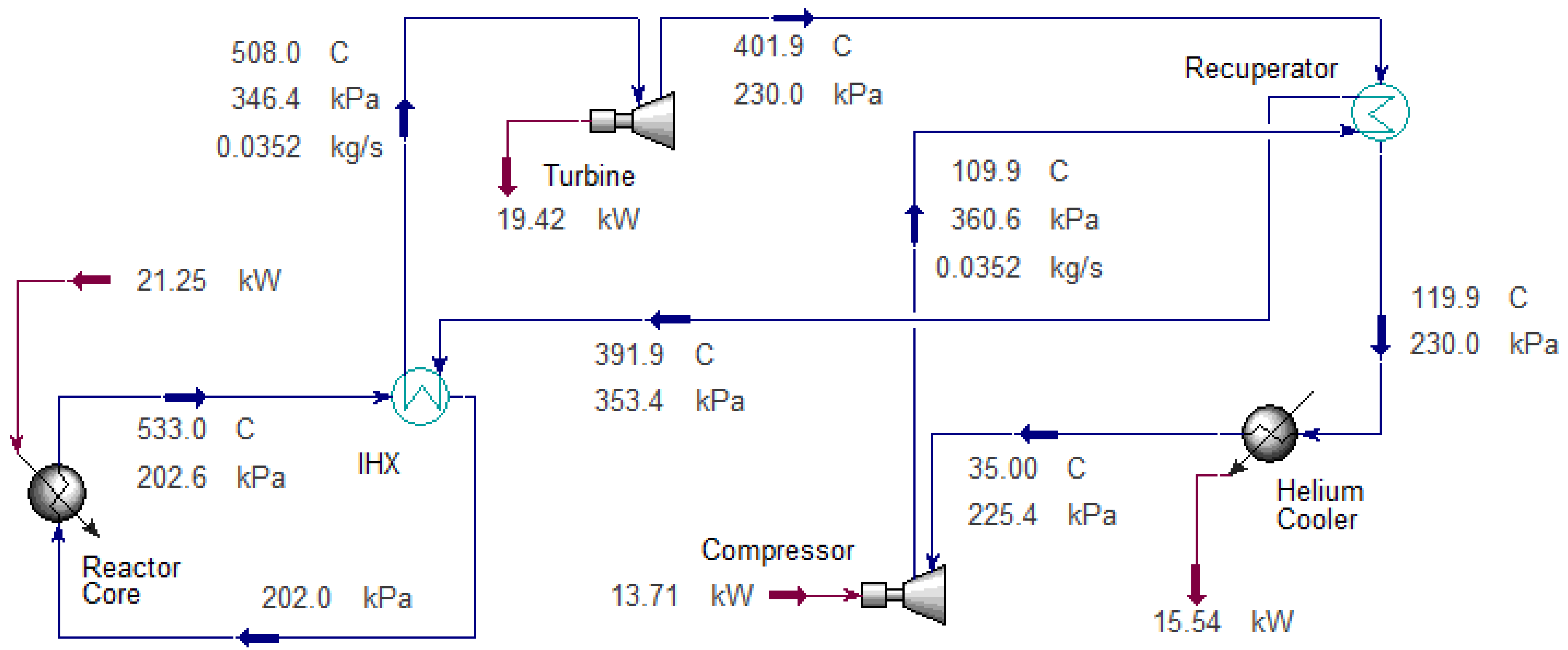
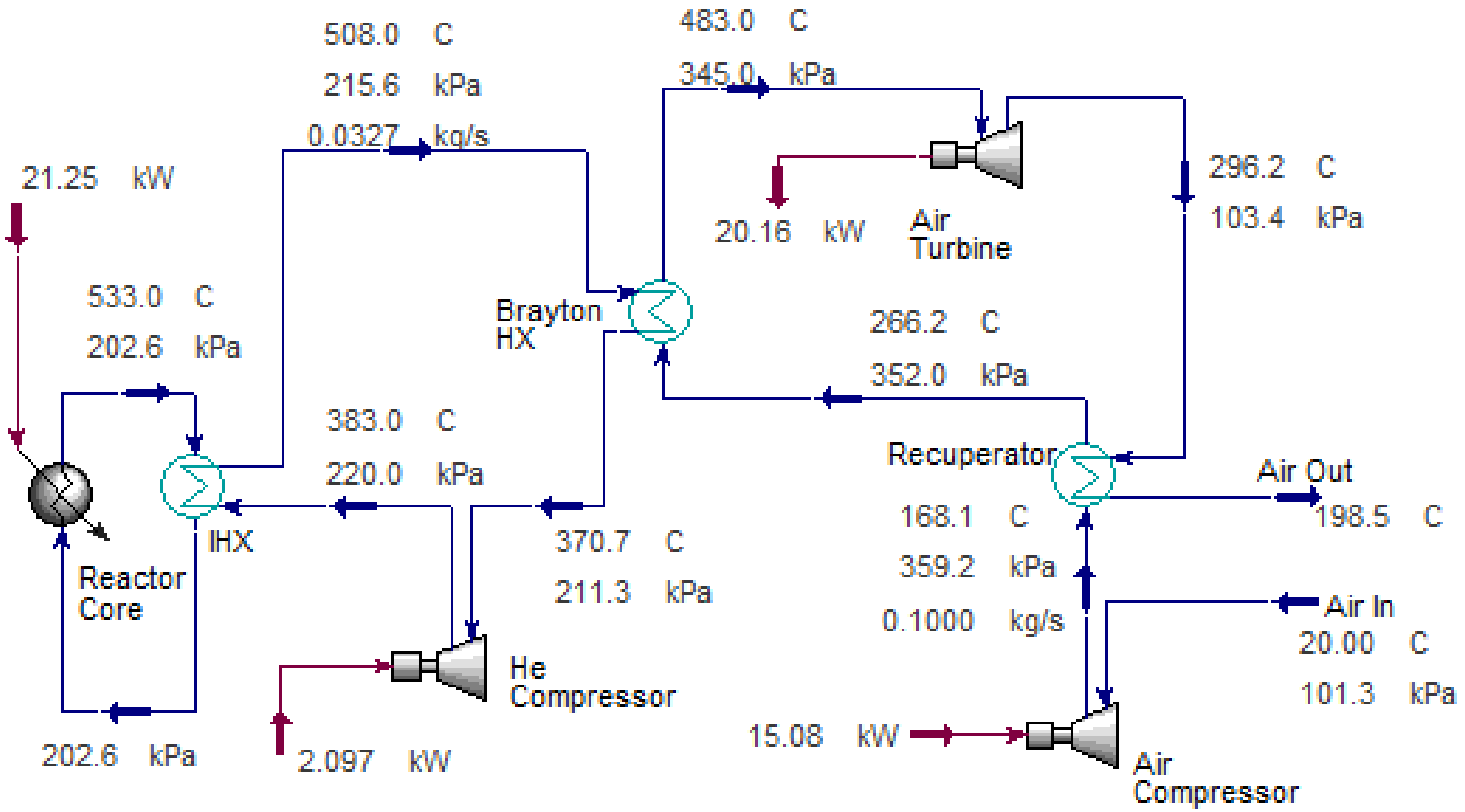
Closed Helium Brayton Cycle with Recuperation.



- Observations:
  - Reasonably mature
  - Simple, with relatively low capital costs
  - Second most common cycle among MRP developers
  - Excellent improvement in thermal efficiency for lower heat sink temperatures

Open Air Brayton Cycle with Recuperation and Intermediate Loop



- Observations:
  - Least efficient cycle – significant penalty from 2 compressors
  - Second most common cycle among MRP developers
  - Excellent improvement in thermal efficiency for lower heat sink temperatures – not enough to overcome work needed for air compressor

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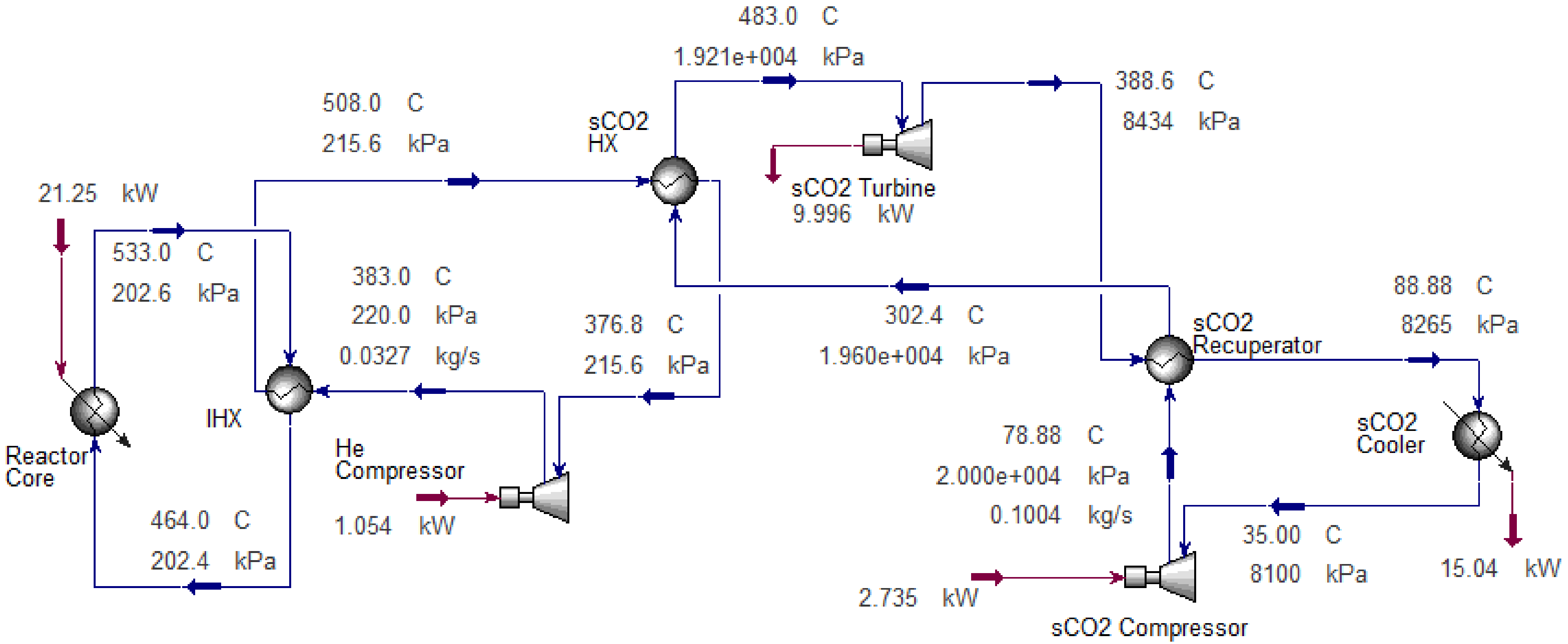
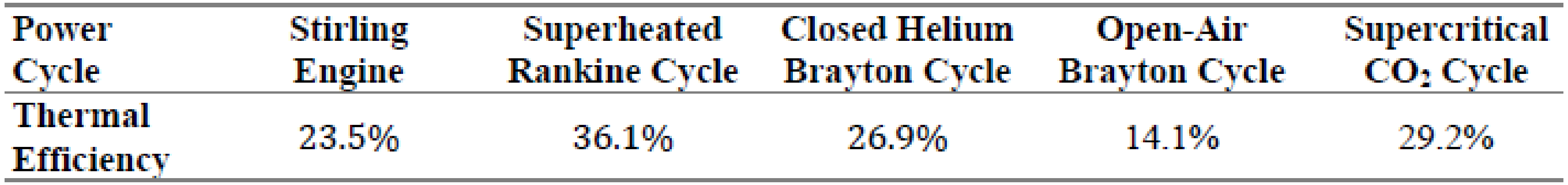
sCO_2 Cycle with Recuperation



- Observations:
  - Good efficiency, least technically mature
  - Limited efficiency gain for lower heat sink temperatures

Summary

- Results - Comparison of Thermal Efficiency [$(\eta_{th} = \sum(W_{net})/\sum(Q_{reactor}) \times 100\%$]



Power Cycle	Stirling Engine	Superheated Rankine Cycle	Closed Helium Brayton Cycle	Open-Air Brayton Cycle	Supercritical CO_2 Cycle
Thermal Efficiency	23.5%	36.1%	26.9%	14.1%	29.2%

- Analysis
  - All options, configured with an intermediate He loop, solve corrosion, radiation, and thermal stress limitations associated with Stirling engines
  - Stirling engines are less thermally efficient than all but the Open-Air Brayton Cycle
- Recommendations
  - Leverage models to demonstrate alternative power conversion cycles with MARVEL
  - Expand models to integrate heat applications and wind/solar microgrid
  - Expand models to include other microreactor types

Questions?