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# Modeling and Economic Analysis of SCO2 Power Systems Hybridized with a Gas Turbine

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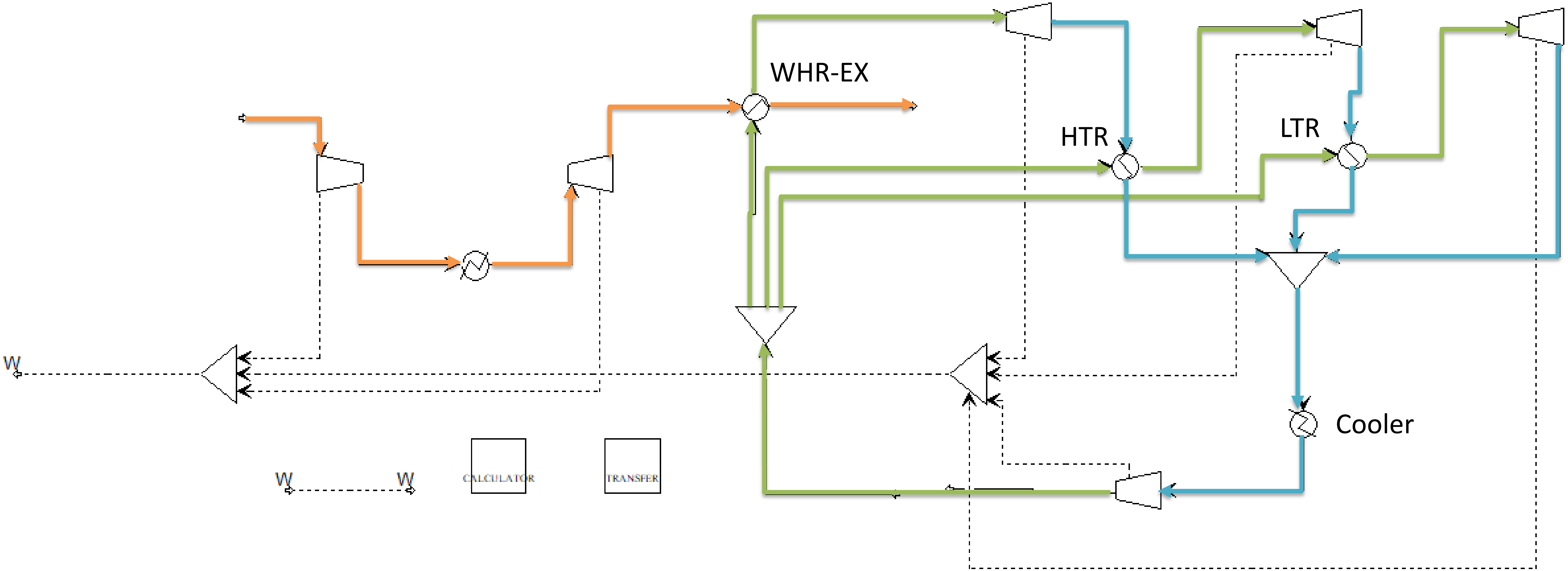
# Motivation

- Explore the hypothesis of cost and performance efficiency for Gas turbines in combined cycle with SCO2
- Ground the assessment with existing turbines and limiting SCO2 components/complexity
- Microgrid (20-30 MW) scale
  - Apply to systems like the SwRI campus
  - Load following and operates off-design
- Utility (about 1 GW) scale
  - Compare to DOE baselines
  - Operates as a on-design baseload with a 15% downtime through the year

# Approach

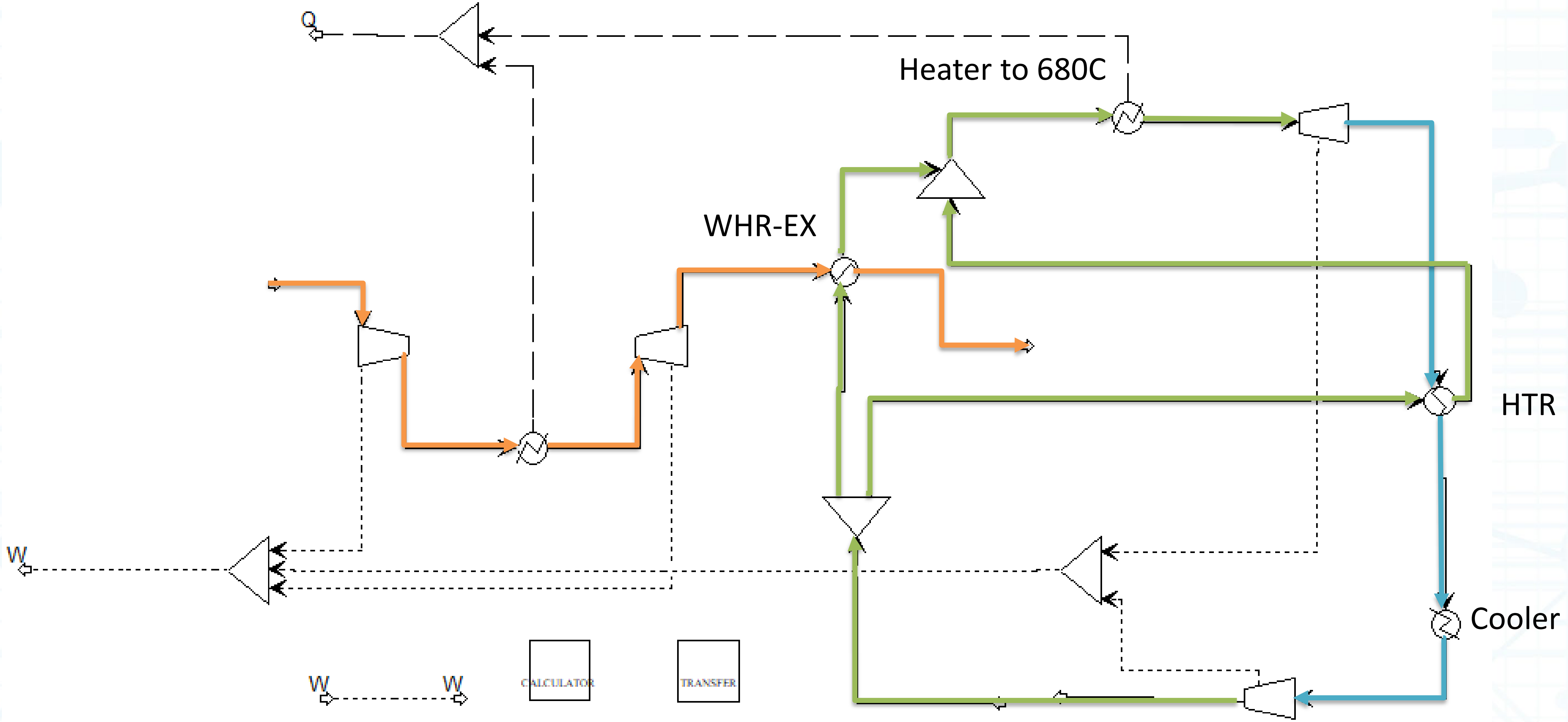
- Pick a gas turbine generator as a consistent size and build an SCO2 cycle that uses the waste heat from the combustion turbine
- Model in Aspen Plus with REFPROP properties
- Use literature sources for combustion turbine performance and waste hot gas flow rate/composition
  - NETL baseline for utility-scale H-Class gas turbine combined cycle (GTCC)
  - NETL indirect SCO2 baseline also used to assess cost/performance of SCO2 cycles
  - EPA Study of small combustion turbines for the small system case
- Seek to maximize heat from gas turbine exhaust heat and minimize pinches in heat exchangers

# Dual Cascaded (DC) Cycle




Combustion Turbine Gas
High Pressure SCO2
Low Pressure SCO2

# Preheat, Recuperation, Overheat (PRO) Cycle




Combustion Turbine Gas
High Pressure SCO2
Low Pressure SCO2

# System Design Assumptions

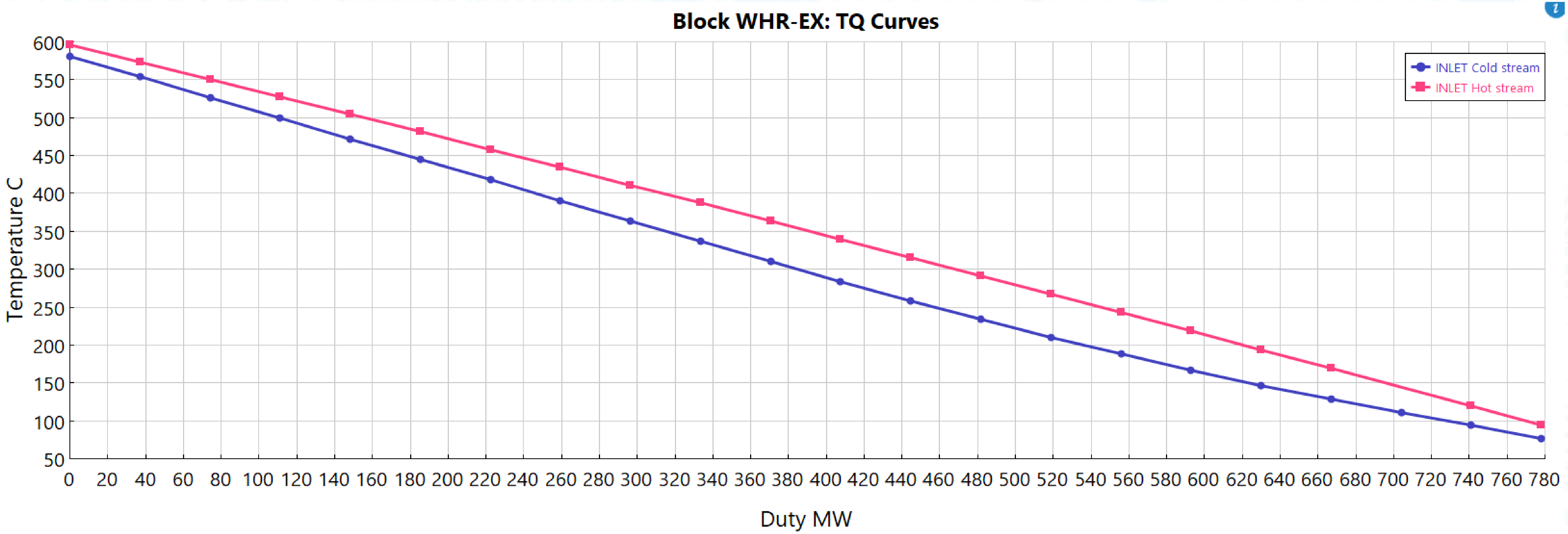
- 15°C approach temperature in waste heat recovery exchanger
- 10°C approach temperature in recuperators and coolers
- Ambient temperature is 25°C
- SCO2 turbines are 90% isentropic efficiency
- SCO2 compressors are 80% isentropic efficiency
- 85 bar as the compressor inlet pressure
- Different compressor outlet pressures due to exchanger tuning
  - DC cycle: 300 bar
  - PRO cycle: 380 bar

# Performance Results

- Fixed GT capacity for the different scales
  - Small GT exhaust: 586°C
  - Large GT exhaust: 596°C
- In DC cycle the SCO2 system capacity is around half the size of the GT
- In PRO cycle the SCO2 system capacity is similar to the GT size
  - Note that PRO cycle efficiency shown is for standalone operation

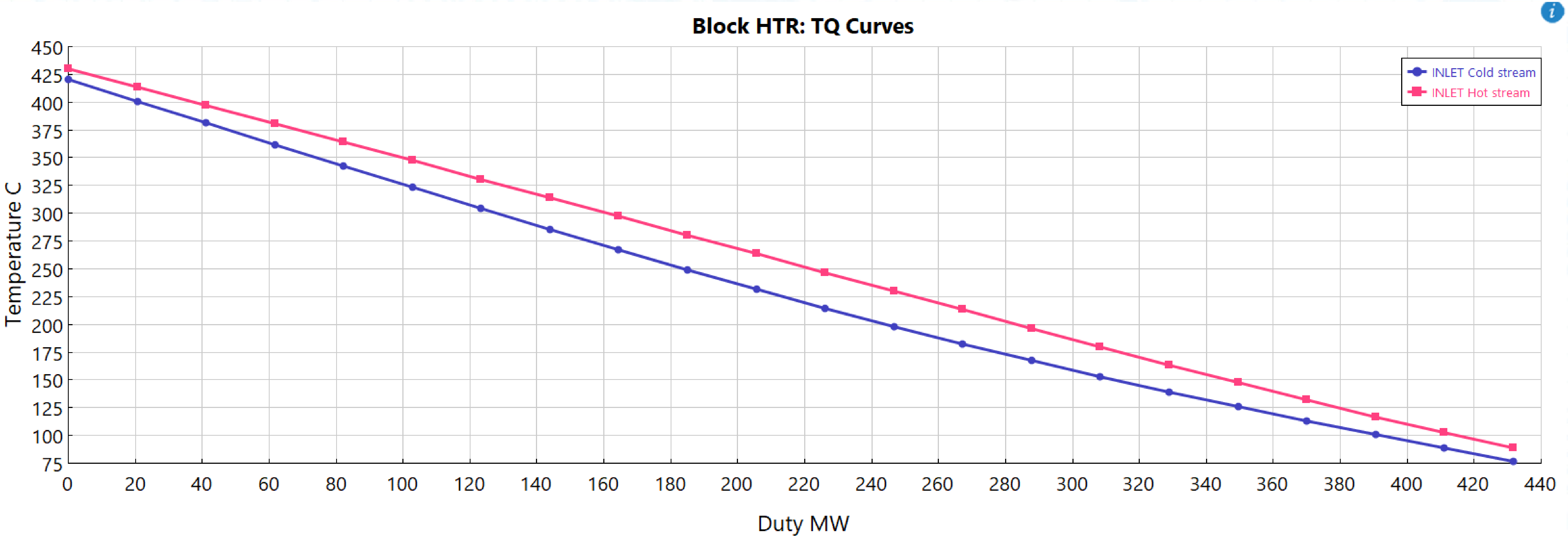
| | Small GT with DC Cycle | Small GT with PRO Cycle | H-Class GT with DC Cycle | H-Class GT with PRO Cycle |
|---|---|---|---|---|
| GT Efficiency (%) | 39.1% | 39.1% | 43.8% | 43.8% |
| GT Output Size (kW) | 13,962 | 13,962 | 685,495 | 685,495 |
| SCO2 Efficiency (%) | 31.9% | 39.1%* | 32.4% | 39.2%* |
| SCO2 Output Size (kW) | 5,890 | 15,074 | 252,139 | 603,320 |
| System Total Output Size (kW) | 19,852 | 29,036 | 937,634 | 1,288,815 |
| Combined System LHV Thermal Efficiency (%) | **55.6%** | **52.4%** | **59.8%** | **55.0%** |
| *Note that the SCO2 PRO cycle efficiency is in standalone operation assuming heat through the WHR-EX is provided externally and not by the GT exhaust | | | | |

# DC Cycle Waste Heat Exchanger Profile (H-Class)



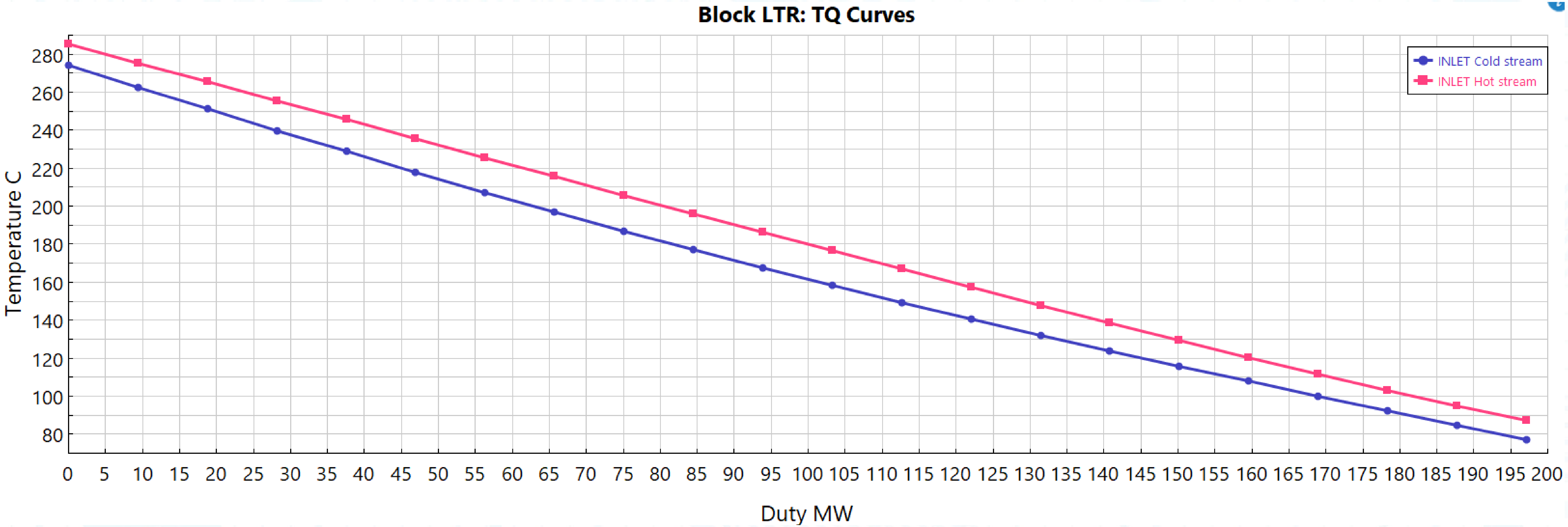

- 15°C approach at Hot end with 18°C difference on cold
- Small GT: cold end difference is 37 °C

# DC Cycle High Temperature Recuperator (H-Class)




- 10°C approach at Hot end with 12°C difference on cold
- Small GT: Hot inlet is lower at 421°C with a 14°C difference on cold

# DC Cycle Low Temperature Recuperator (H-Class)

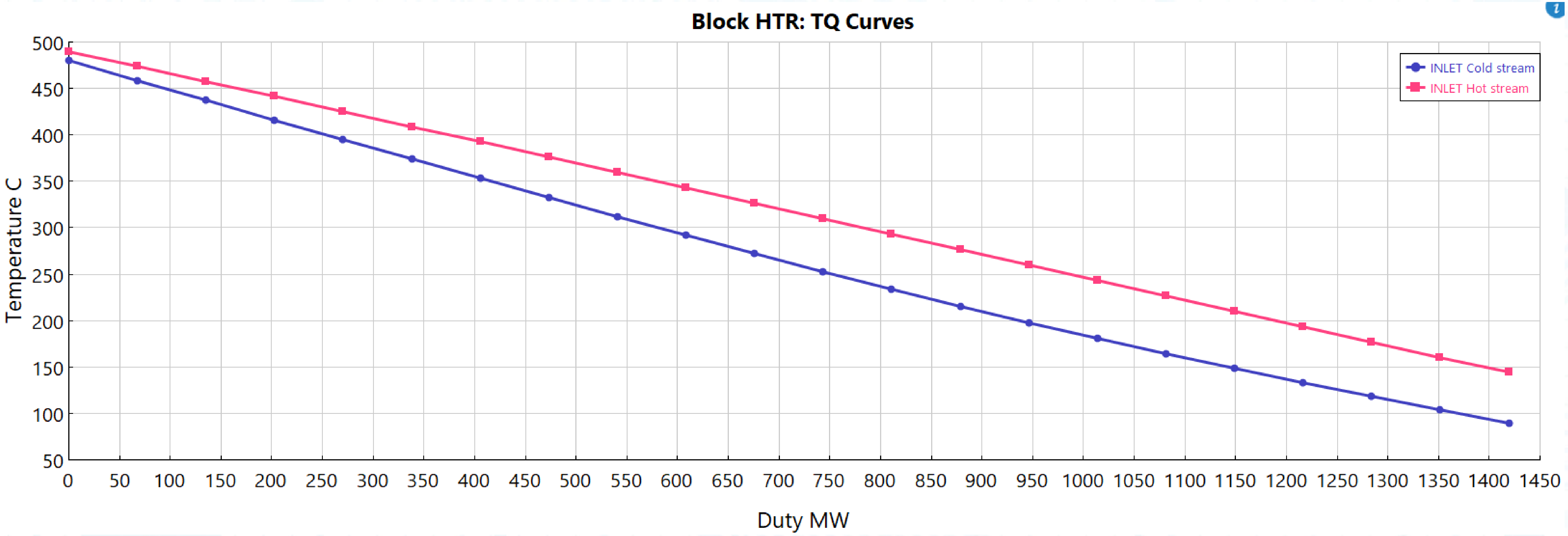



- 10°C approach at Hot end with 11°C difference on cold
- Small GT: Hot inlet is lower at 273°C with a 13°C difference on cold
- CO2 Cooler Inlet Temperatures: 102°C and 101°C for large GT and small GT

# PRO Cycle Waste Heat Exchanger Profile (H-Class)


- 15°C approach at Hot end with 18°C difference on cold
- Small GT: cold end difference is 37°C

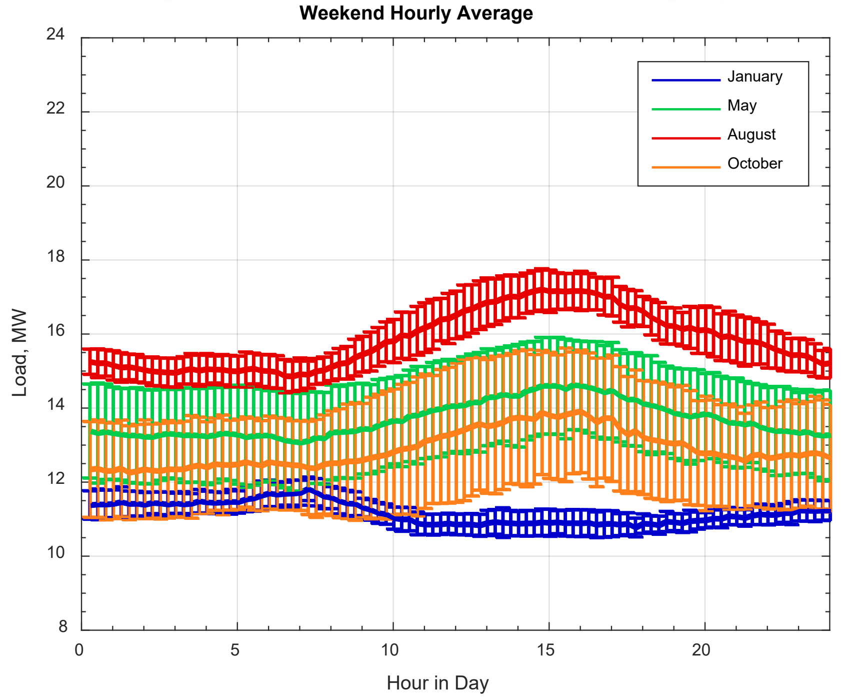
# PRO Cycle Recuperator (H-Class)

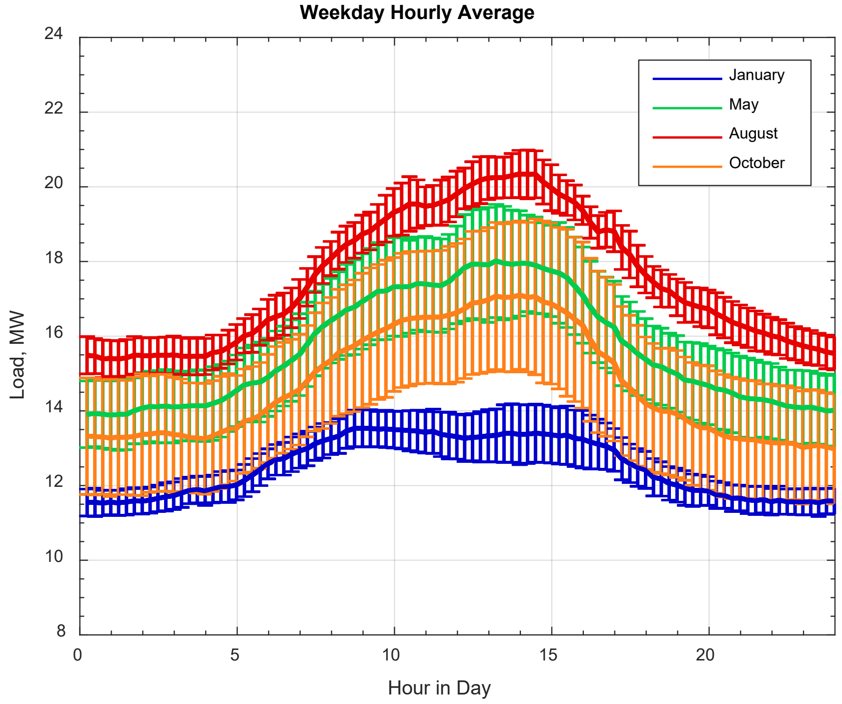



- 10°C approach at Hot end with 55°C difference on cold
- Small GT: Similar profile
- Entering cooler at 150°C

# Target Application

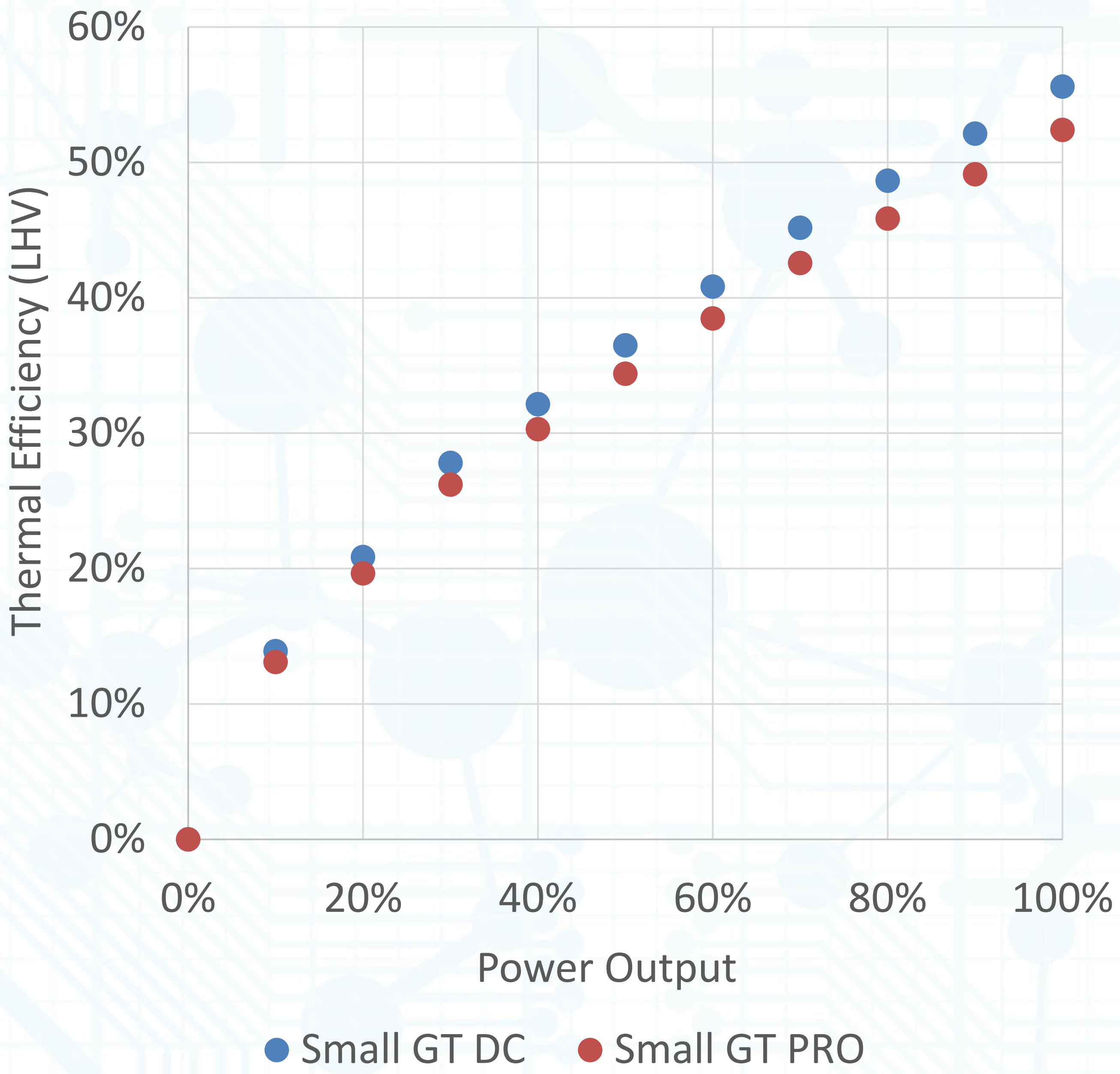
- Utility Scale
  - Match NETL baseline profile
  - Baseload with constant power output at full capacity
- Microgrid Scale
  - Used a representative profile, SwRI campus electric load
  - Higher peaks in summer and work days
  - Scaled max power in the profile to match the overall system maximum power output



# Off-Design

- Off-design needed for microgrid load-following operation
- Profile adopted from literature and scaled to on-design efficiency
- Future work will build an off-design curve from sized equipment in Aspen Plus
  - Will feed into a more detailed economic estimate



# Techno-Economic Assessment Inputs

- System costs built from literature on total installed cost
  - Sources that detail the cost by component
  - Components that were not present were removed, such as a recompressor

| | Small GT with DC Cycle | Small GT with PRO Cycle | H-Class GT with DC Cycle | H-Class GT with PRO Cycle |
|---|---|---|---|---|
| GT System Capacity Cost ($/kW$_{AC}$) | 1,510 | 1,510 | 771 | 771 |
| SCO2 System Capacity Cost ($/kW$_{AC}$) | 2,900 | 2,900 | 2,130 | 2,087 |
| Combined Capacity Cost ($/kW$_{AC}$) | 1,946 | 2,232 | 1,137 | 1,388 |

- EPC costs based on baselines at 20%
- 30 year system with 20 year payback with 71.8% financed at 5% fixed rate
- Natural gas cost of $ 4.64 $/GJ$_{LHV}$
- LCOE follows discounted cash flows
  - 2.5% inflation
  - 5.1% real discount rate

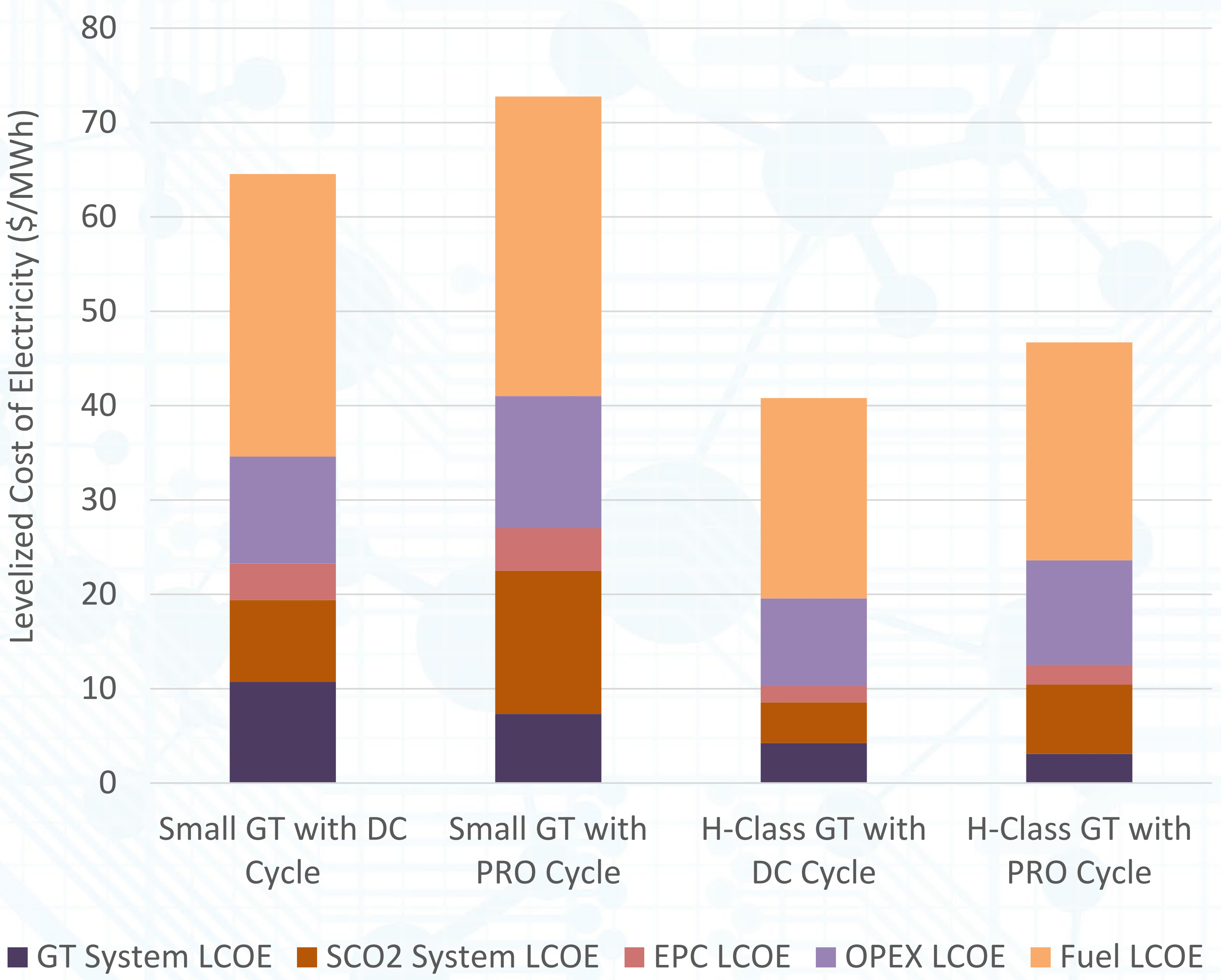
| | | |
|---|---|---|
| GT Fixed OPEX | 26 | $/kW |
| GT Variable OPEX | 1.2 | $/MWh |
| SCO2 Fixed OPEX | 113 | $/kW |
| SCO2 Variable OPEX | 4.4 | $/MWh |

# Cost Results for Systems

| | Small GT with DC Cycle | Small GT with PRO Cycle | H-Class GT with DC Cycle | H-Class GT with PRO Cycle |
|---|---|---|---|---|
| CAPEX GT System | $21.1 M | $21.1 M | $528.8 M | $528.8 M |
| CAPEX SCO2 System | $17.1 M | $43.7 M | $537.1 M | $1,259.4 M |
| CAPEX Combined System | $38.2 M | $64.8 M | $1,066.0 M | $1,788.3 M |
| EPC and Owner's Costs | $7.6 M | $13.0 M | $213.2 M | $357.7 M |
| Total CAPEX | **$45.8 M** | **$77.8 M** | **$1,279.2 M** | **$2,145.9 M** |
| | | | | |
| OPEX GT System | $0.5 M | $0.6 M | $26.2 M | $29.3 M |
| OPEX SCO2 System | $1.2 M | $2.4 M | $59.2 M | $110.4 M |
| Total OPEX | **$1.6 M** | **$3.0 M** | **$85.4 M** | **$139.7 M** |
| | | | | |
| Annual Payment for 20-year Financing | $2.6 M | $6.7 M | $195.1 M | $291.6 M |
| | | | | |
| Capacity Factor (%) | 63.4% | 63.4% | 85% | 85% |
| Power Exports (MWh) | 110,301 | 161,330 | 6,981,623 | 9,596,516 |
| Natural Gas Imports ($tonne_{NG}$) | 19,821 | 30,761 | 890,444 | 1,330,768 |
| Annual Fuel Cost ($) | **$4.3 M** | **$6.7 M** | **$195.1 M** | **$291.6 M** |

# Levelized Cost of Electricity

- Initial estimate of LCOE breakdown
  - Not mature enough to match DOE baseline level of detail
- The DOE baseline LCOE
  - Coal SCO2: $123-128/MWh
  - H-Class CCGT $42.7/MWh
- Future work will refine the system design, performance estimate, CAPEX, and OPEX



# Conclusions

- Initial assessment of two different combined cycle configurations each at two different scales
- Applied initial performance results to profiles for the specific applications
  - Load following system in a representative microgrid
  - Baseload utility scale with 85% capacity factor
- All systems were above 55% in cycle efficiency
- Initial estimate of cost and LCOE was assessed based on simple scaling parameters
  - Microgrid LCOE is $65-73/MWh
  - Utility LCOE is $41-47/MWh
- Further work is needed to more closely match baseline methods and refine costs and LCOE estimates

# Thank You