An Assessment of Supercritical CO_2 Power Cycles Integrated with Generic Heat Sources

Chuck White, Noblis

Wally Shelton, NETL

Richard Dennis, NETL

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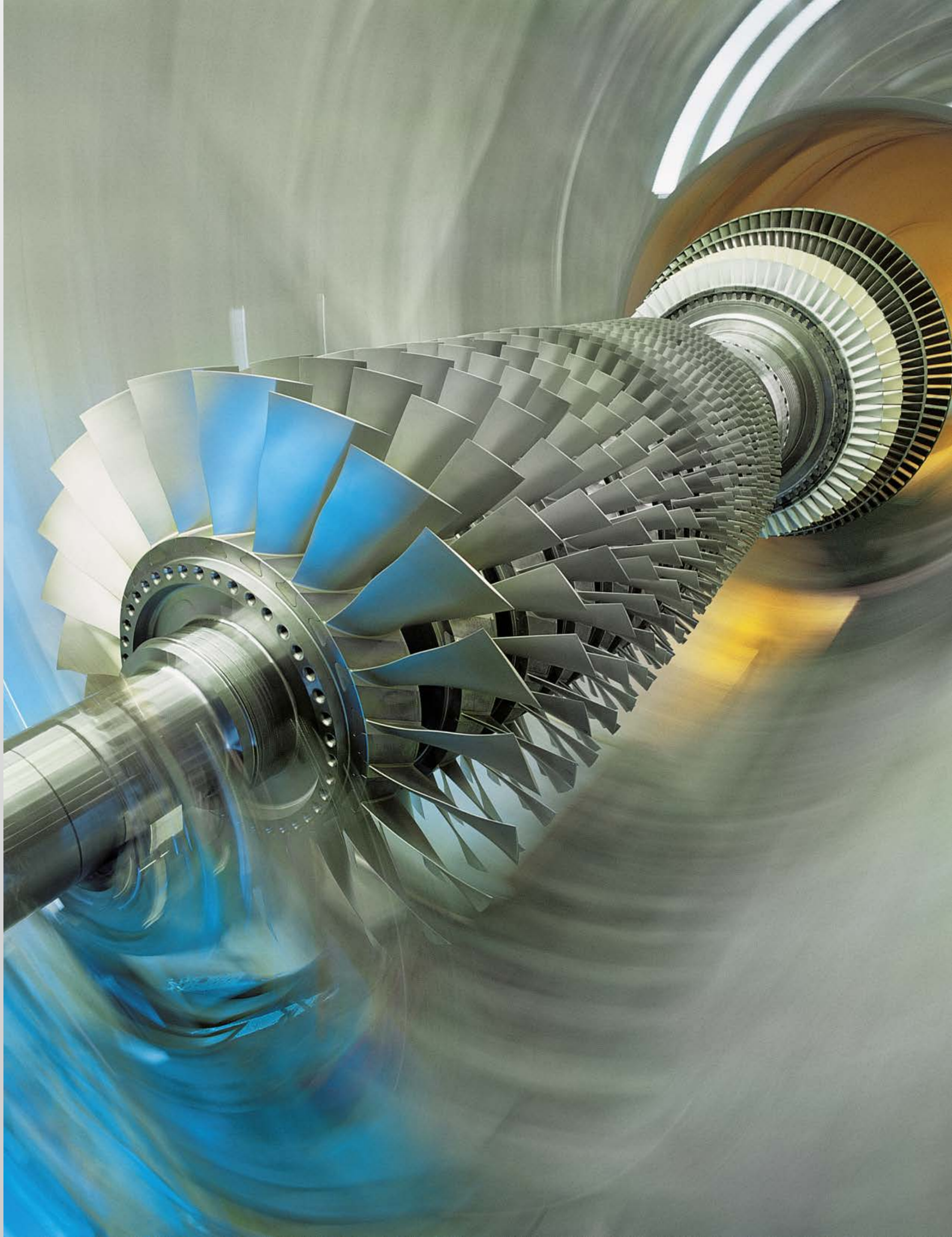
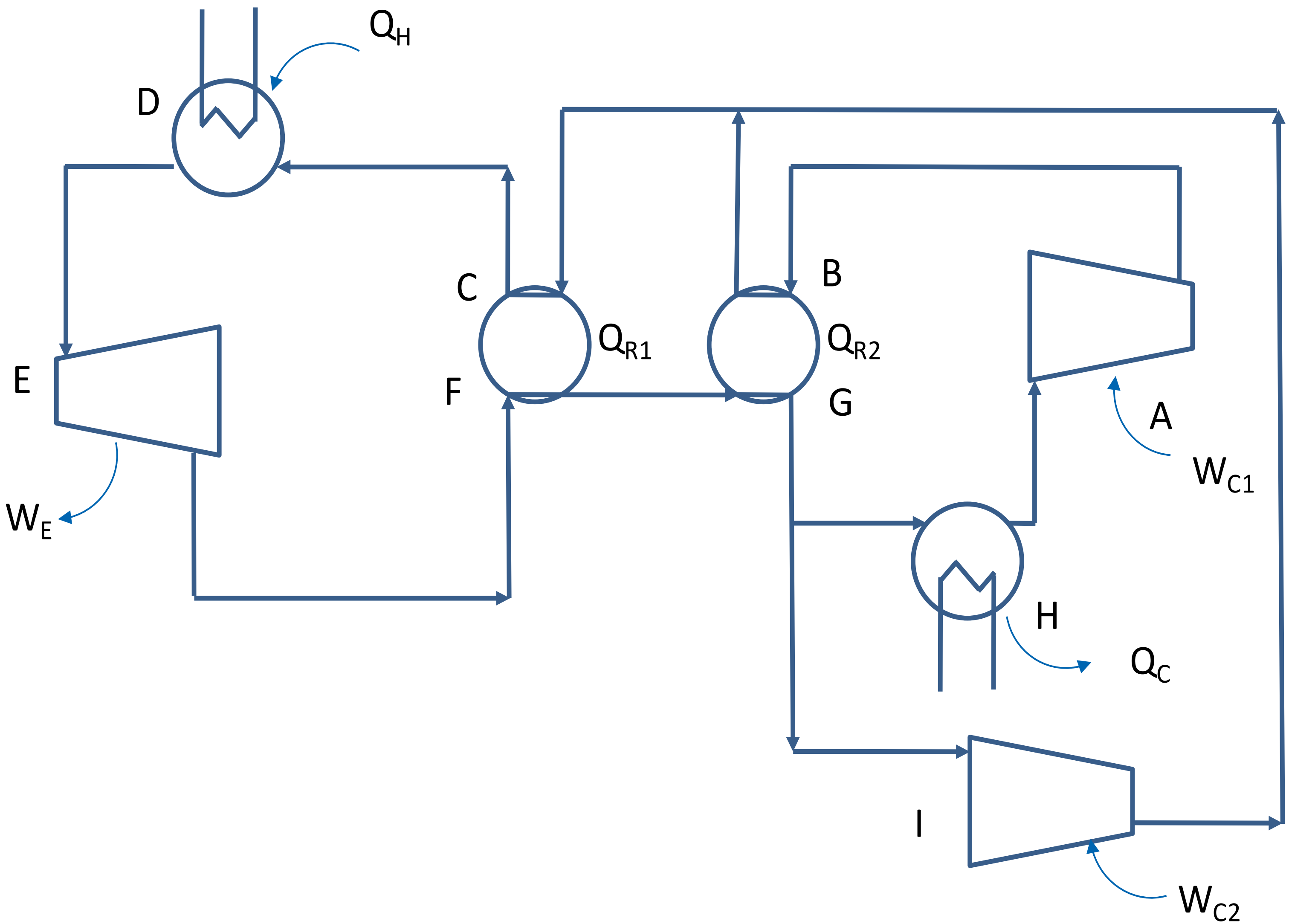


Overview

- **Baseline process – sCO_2 recompression Brayton cycle**
- **Sensitivity analyses: optimizing efficiency**
- **Indirect cost variables**
- **Summary**

Recompression Brayton Cycle

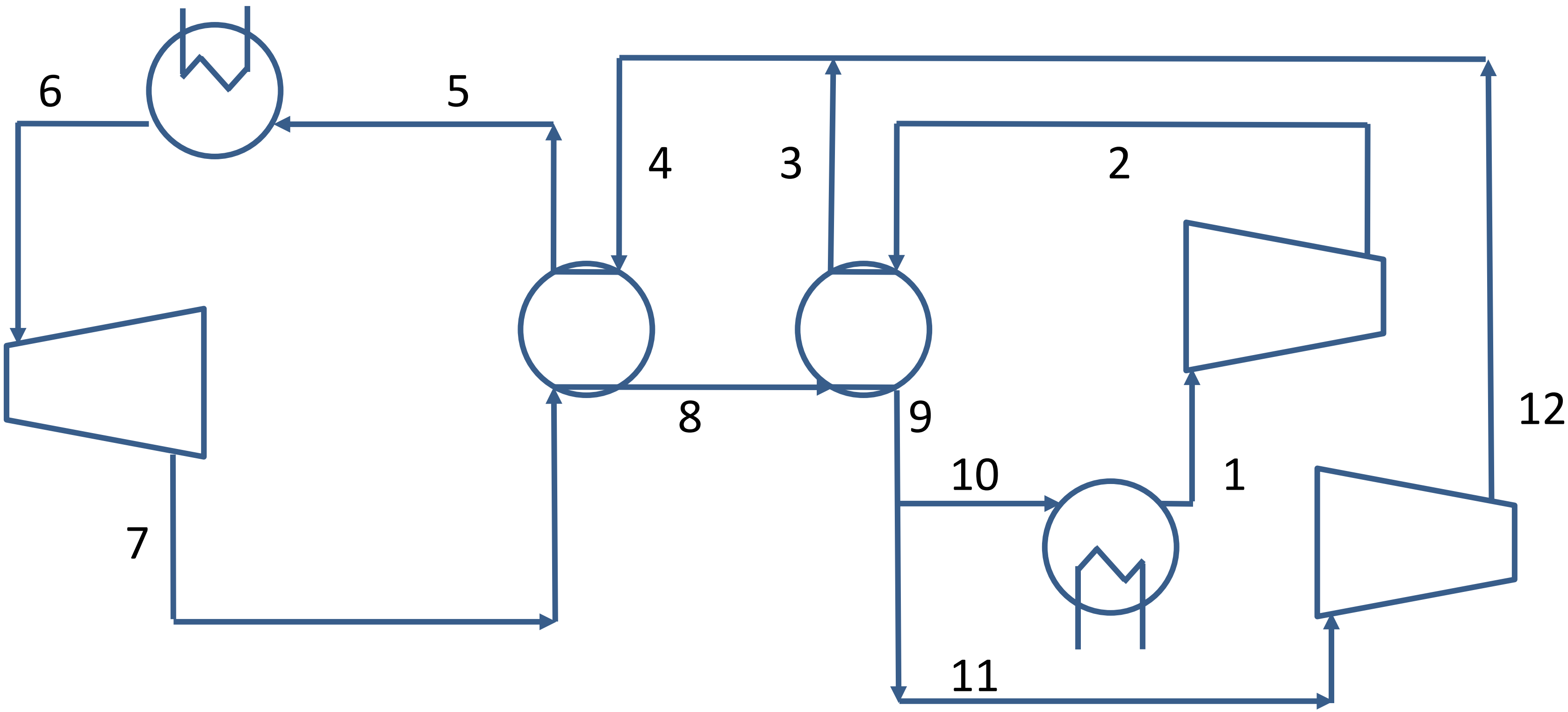


Recompression Brayton Cycle

Parameters for Baseline Cycle

Parameter	Value
Heat source	Generic
Nominal thermal input	64 MMBtu/hr
Turbine exit pressure	1350 psia
CO_2 cooler temperature	35 °C (95 °F)
Turbine isentropic efficiency	0.927
Compressor isentropic efficiency	0.85
Cycle pressure drop	60 psia
Minimum temperature approach	5.6 °C (10 °F)
Turbine inlet temperature	700 °C (1292 °F)
Nominal compressor pressure	5100 psia
Nominal pressure ratio	3.9
Nominal CO_2 cooler bypass fraction	0.283

Recompression Brayton Cycle



Recompression Brayton Cycle

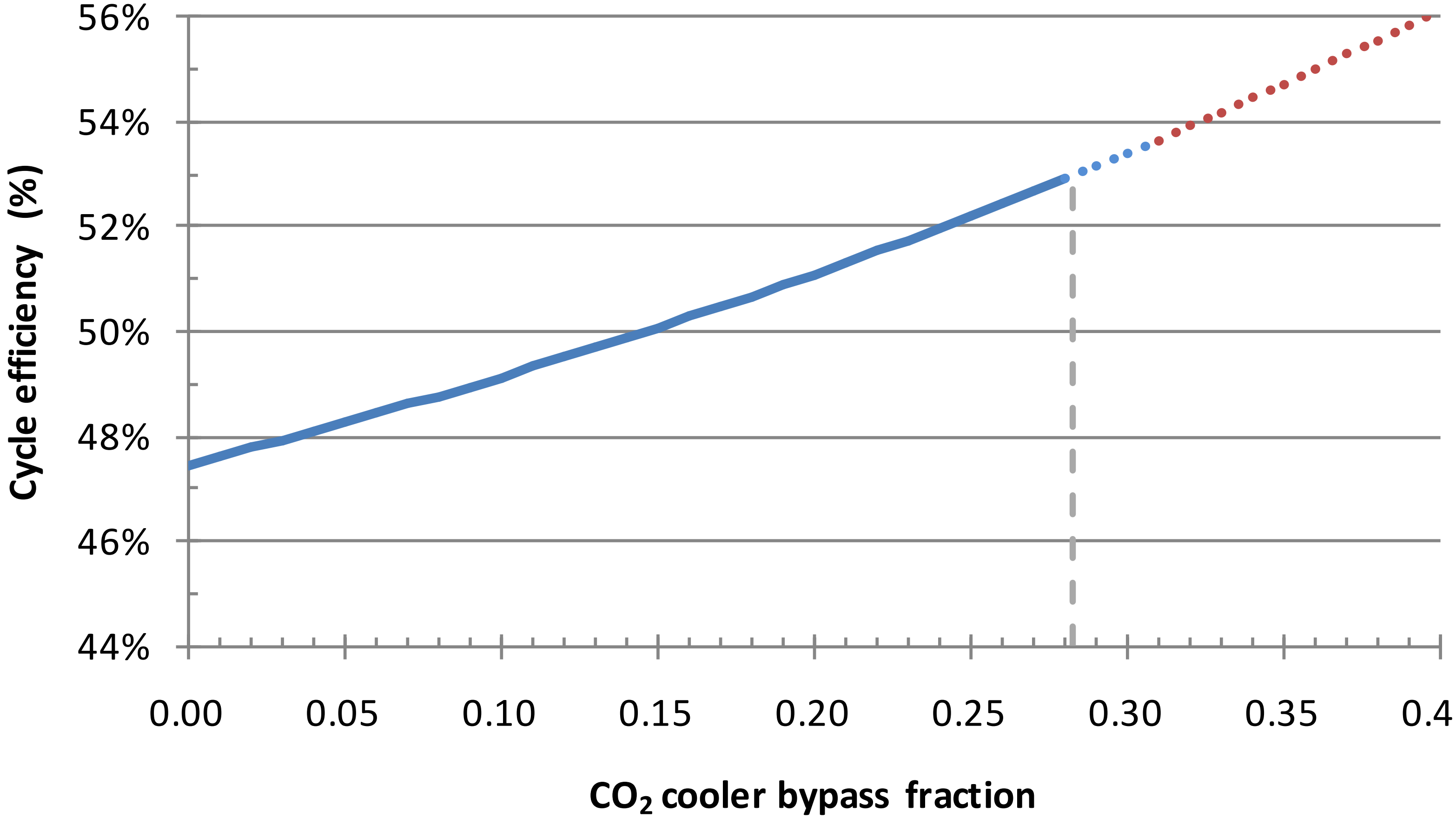
Stream table at compressor pressure 5100 psia

Stream label	1	2	3	4	5	6	7	8	9	10	11	12
Temperature (°F)	95	192.9	452.3	452.3	897.9	1292	978.9	462.3	202.9	202.9	202.9	452.3
Pressure (psia)	1320	5100	5100	5100	5070	5070	1350	1320	1320	1320	1320	5100
Vapor Frac	1	1	1	1	1	1	1	1	1	1	1	1
Mole Flow (lbmol/hr)	8,559	8,559	8,559	11,931	11,931	11,931	11,931	11,931	11,931	8,559	3,372	3,372
Mass Flow (lb/hr)	376,696	376,696	376,696	525,087	525,087	525,087	525,087	525,087	525,087	376,696	148,391	148,391
Volume Flow (ft^3/hr)	10,067	8,066	15,716	21,907	37,210	48,463	139,074	85,320	48,324	34,668	13,657	6,191
Enthalpy (MMBtu/hr)	-1479.74	-1472.52	-1432.04	-1996.16	-1919.66	-1855.25	-1903.45	-1979.95	-2020.43	-1449.45	-570.978	-564.119
Mole Flow (lbmol/hr)												
CO_2	8,559	8,559	8,559	11,931	11,931	11,931	11,931	11,931	11,931	8,559	3,372	3,372

Parameter	Value
Main compressor power (MW)	2.1
Bypass compressor power (MW)	2.0
Turbine power (MW)	14.1
Net power (MW)	10.0
Recuperator stage 1 duty (MMBtu/hr)	76.5
Recuperator stage 2 duty (MMBtu/hr)	40.5
Hot source duty (MMBtu/hr)	64.4
CO_2 cooler duty (MMBtu/hr)	30.3

Recompression Brayton Cycle

Sensitivity to CO_2 cooler bypass fraction



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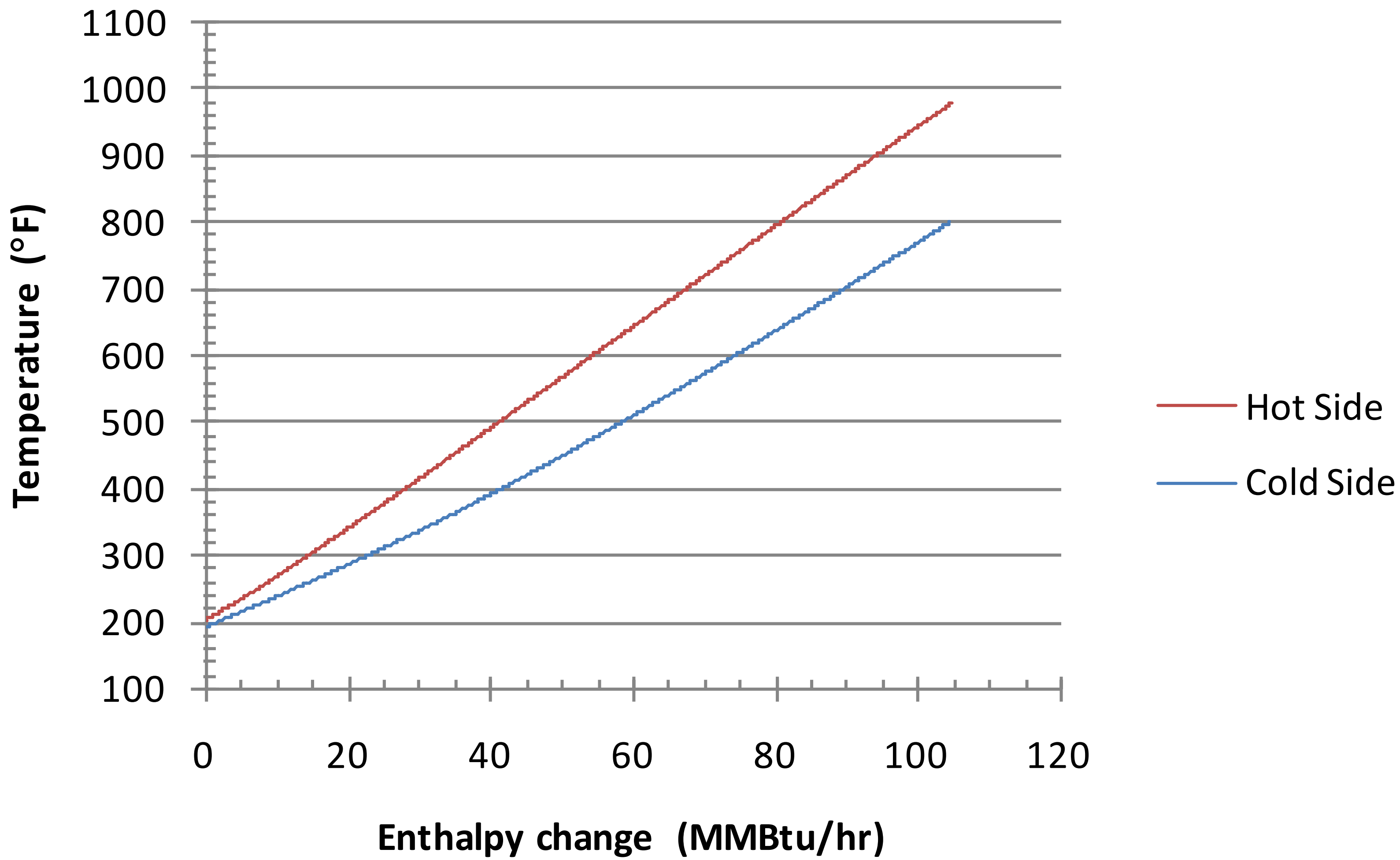
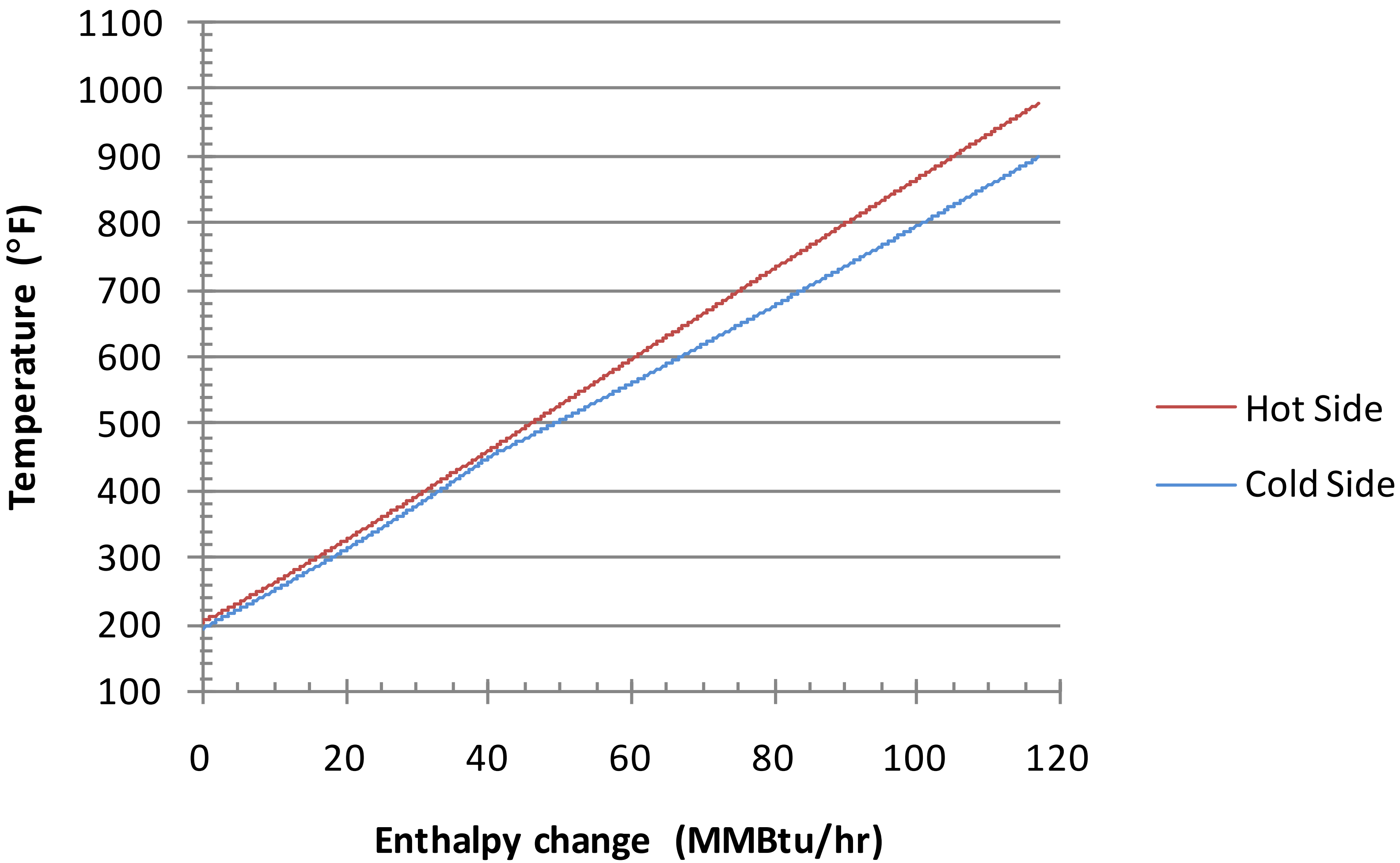
Recompression Brayton Cycle

T-H diagram for recuperated Brayton cycle - bypass fraction = 0.000



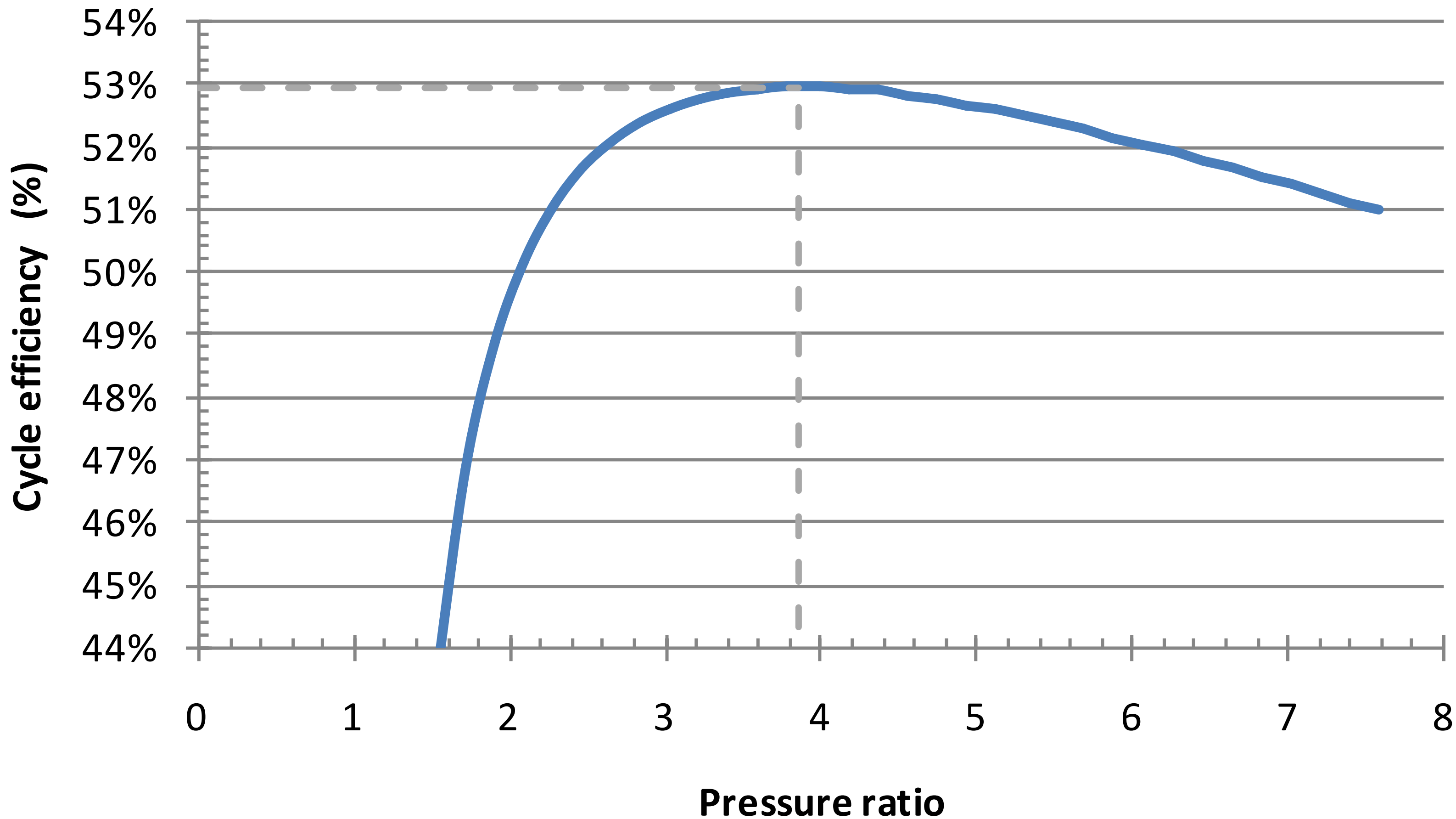
Recompression Brayton Cycle

T-H diagram for recuperated Brayton cycle - bypass fraction = 0.283



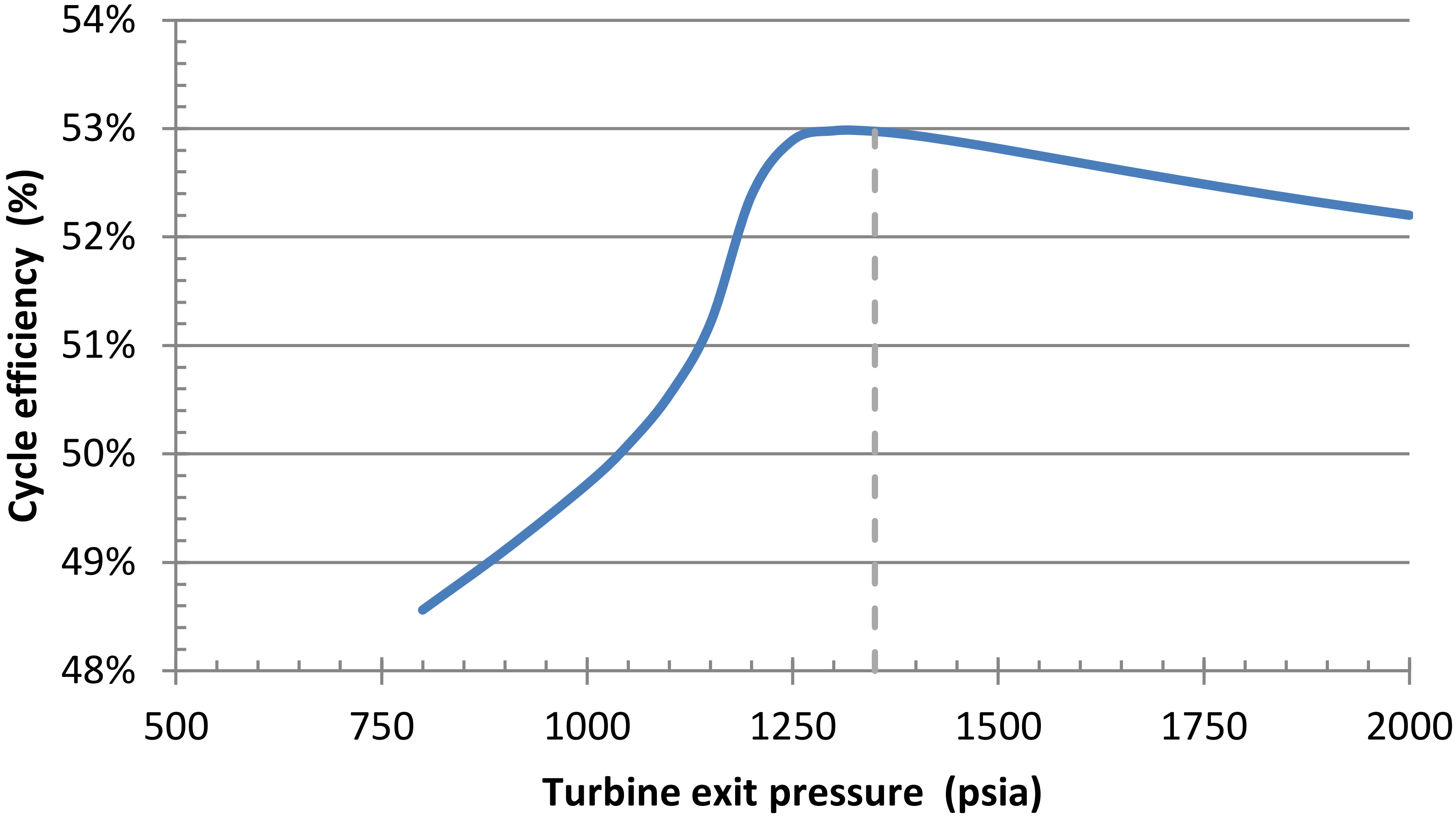
Recompression Brayton Cycle

Sensitivity to pressure ratio



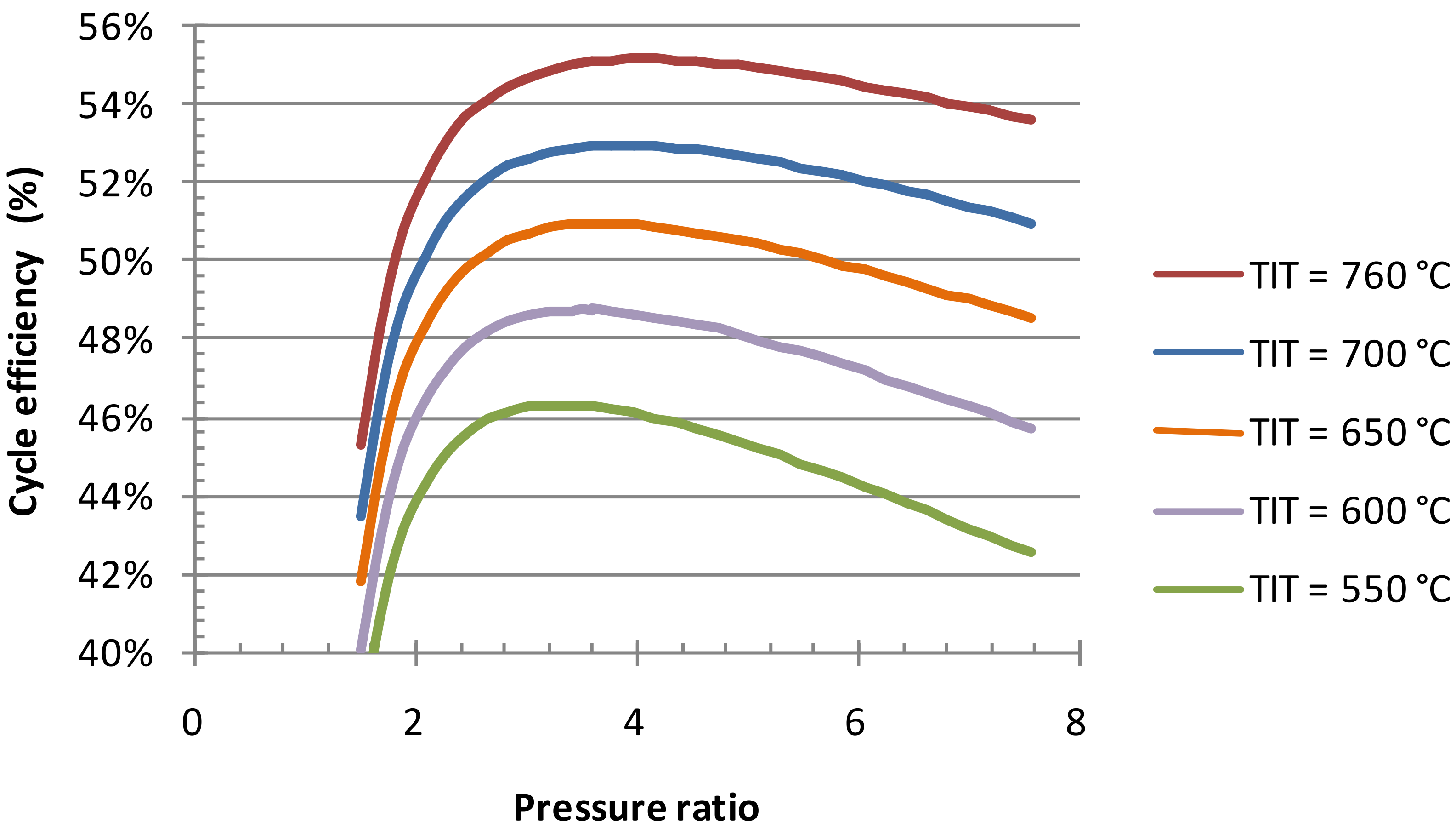
Recompression Brayton Cycle

Sensitivity to turbine exit pressure



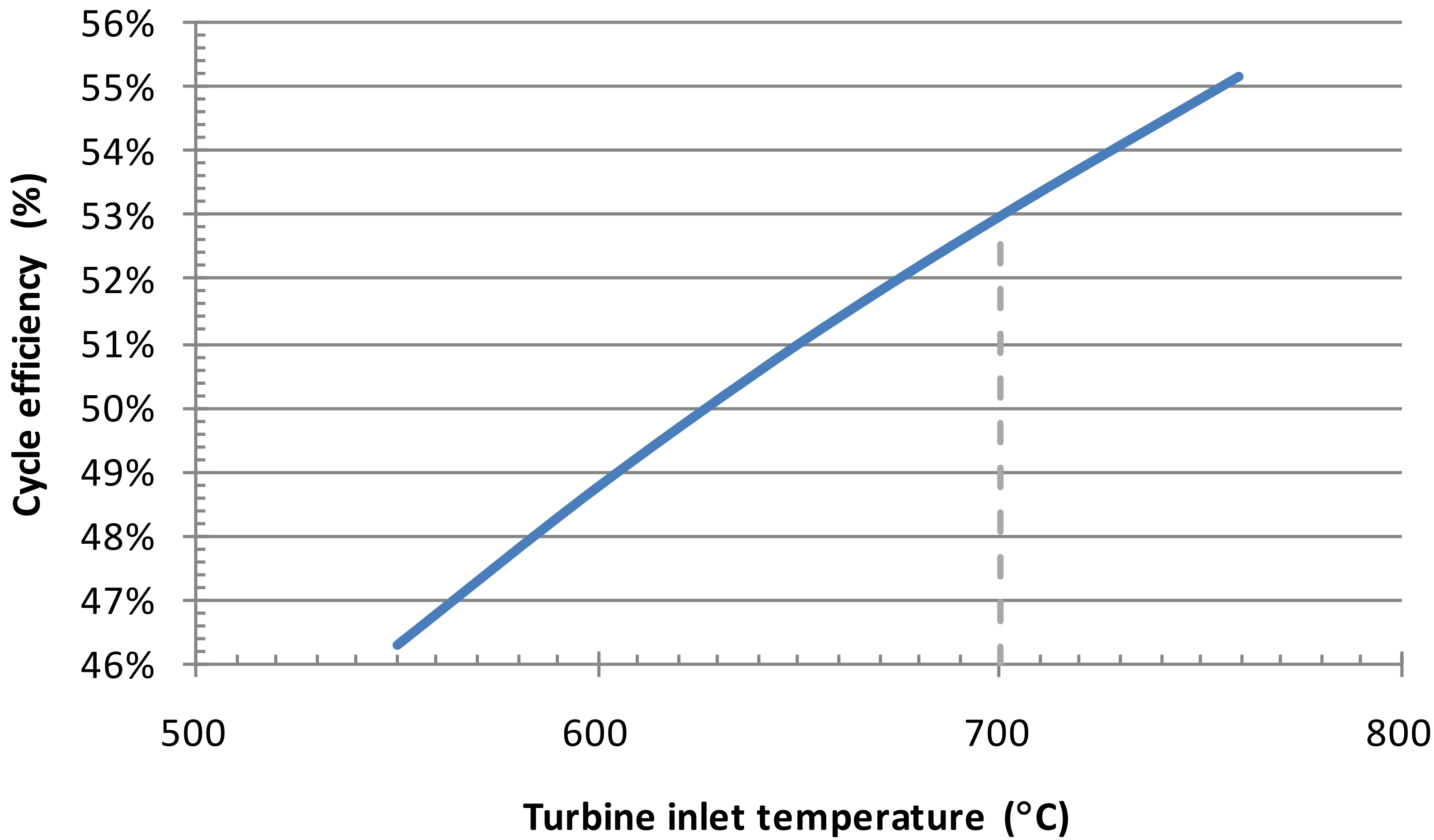
Recompression Brayton Cycle

Sensitivity to turbine inlet temperature



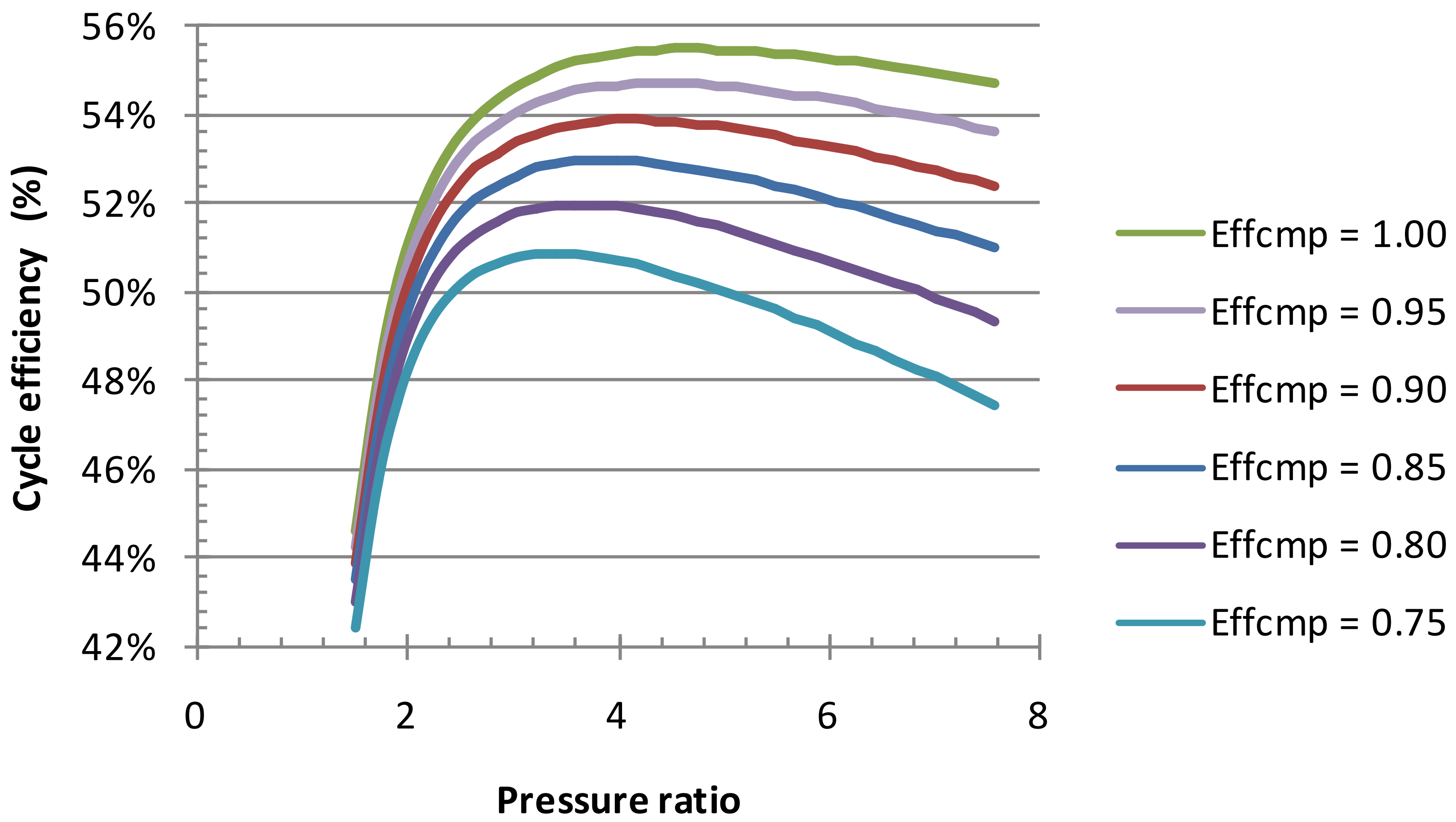
Recompression Brayton Cycle

Sensitivity to turbine inlet temperature



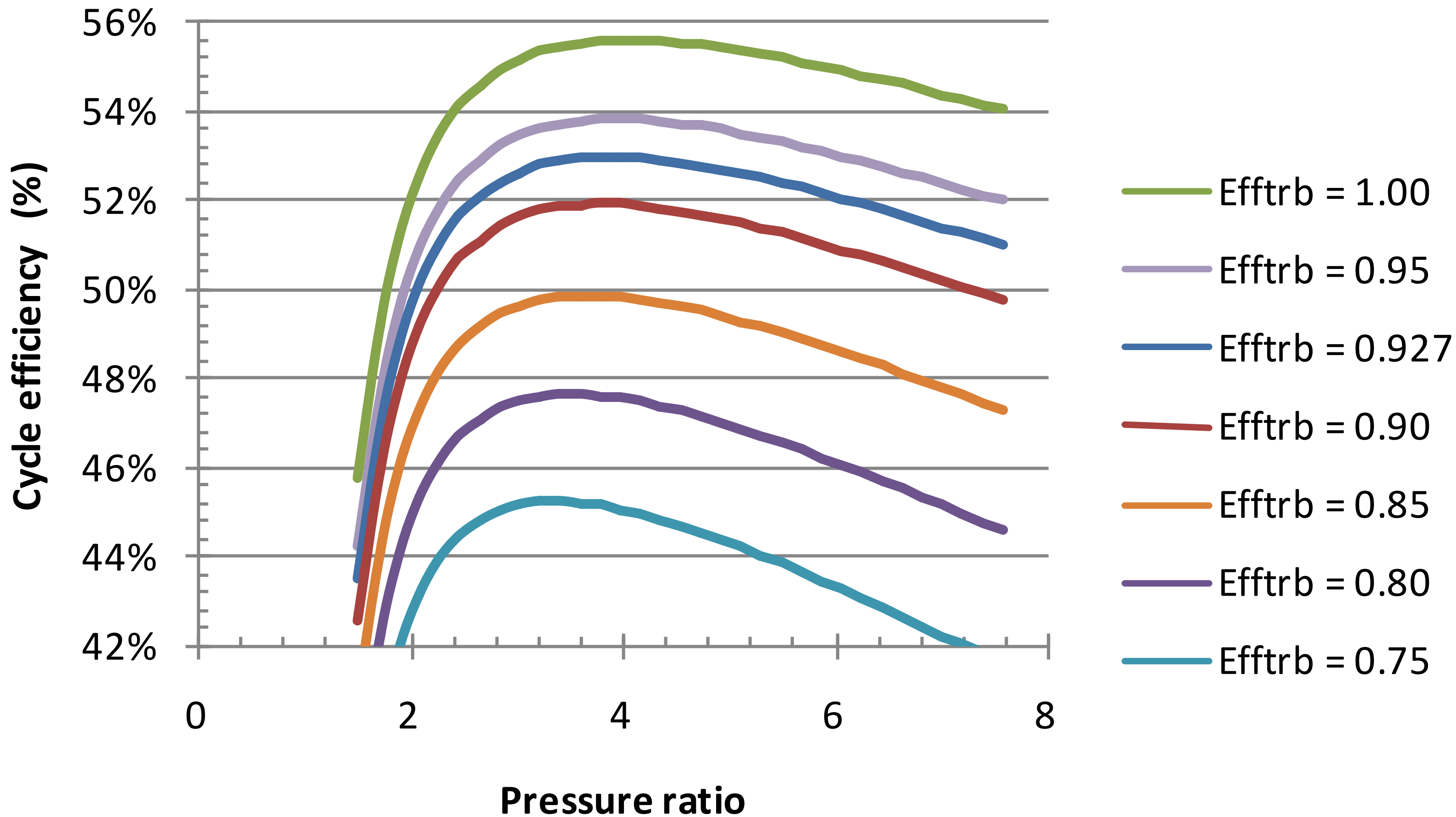
Recompression Brayton Cycle

Sensitivity to compressor efficiency



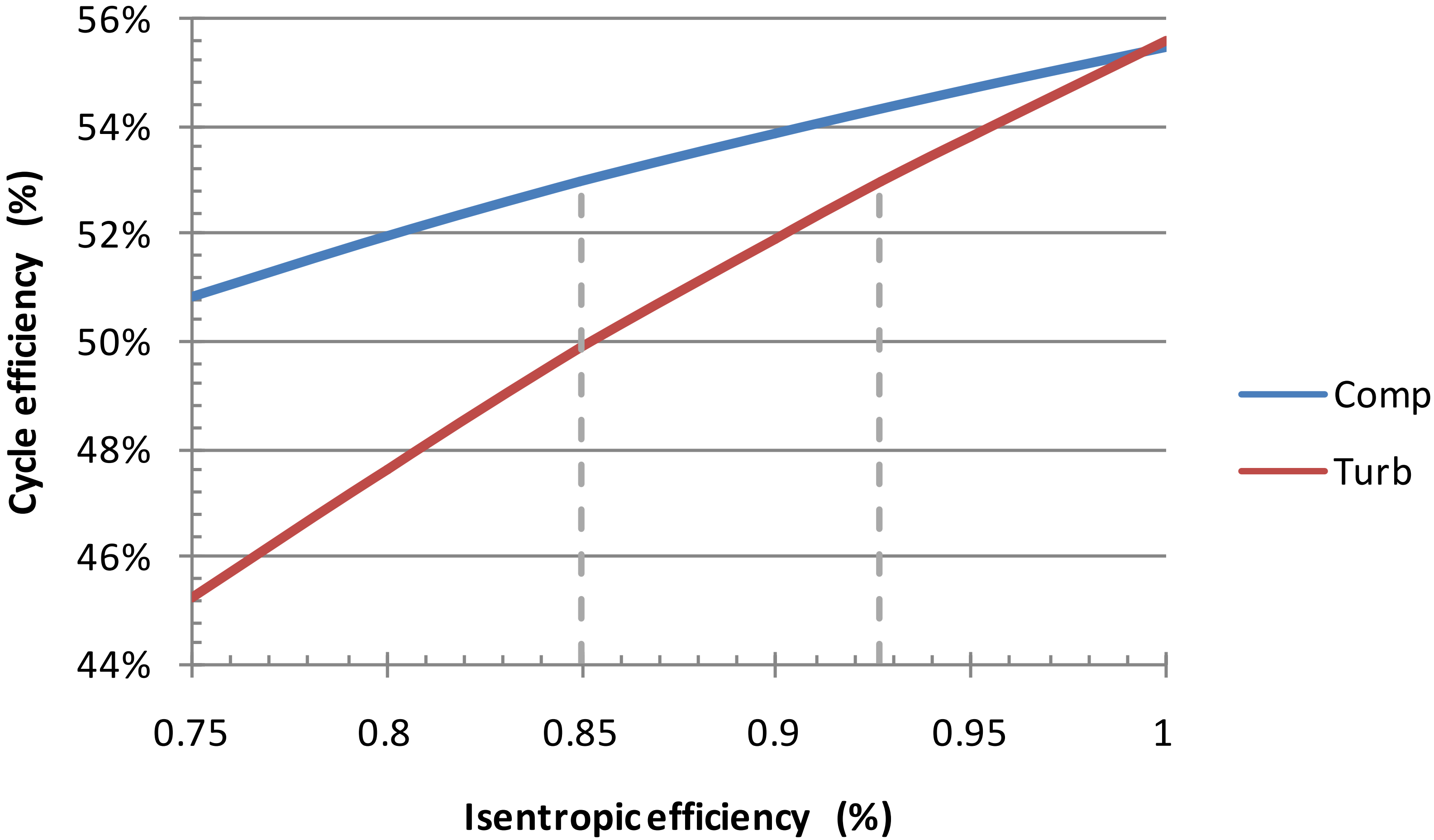
Recompression Brayton Cycle

Sensitivity to turbine efficiency



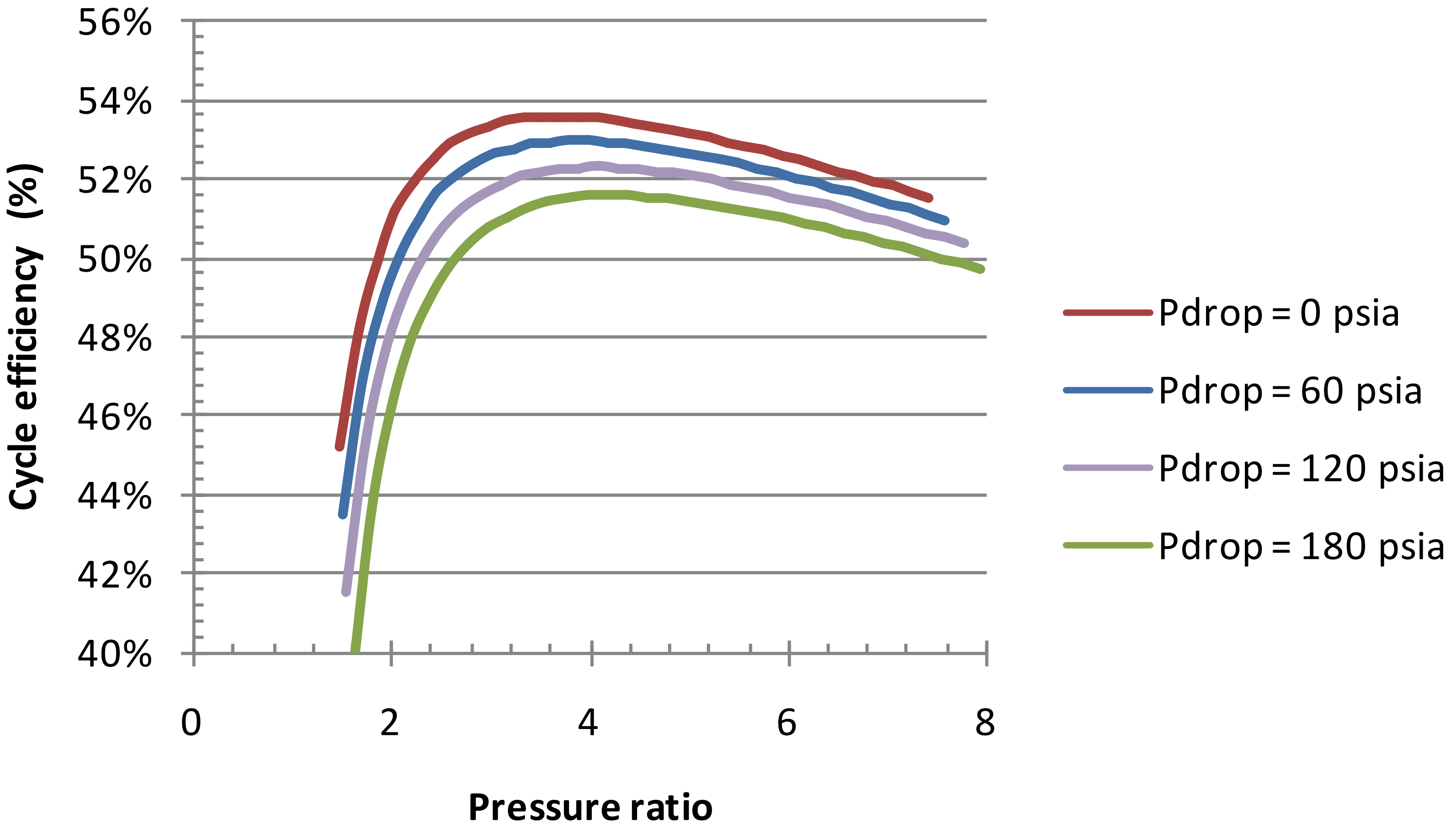
Recompression Brayton Cycle

Sensitivity to turbomachinery efficiency



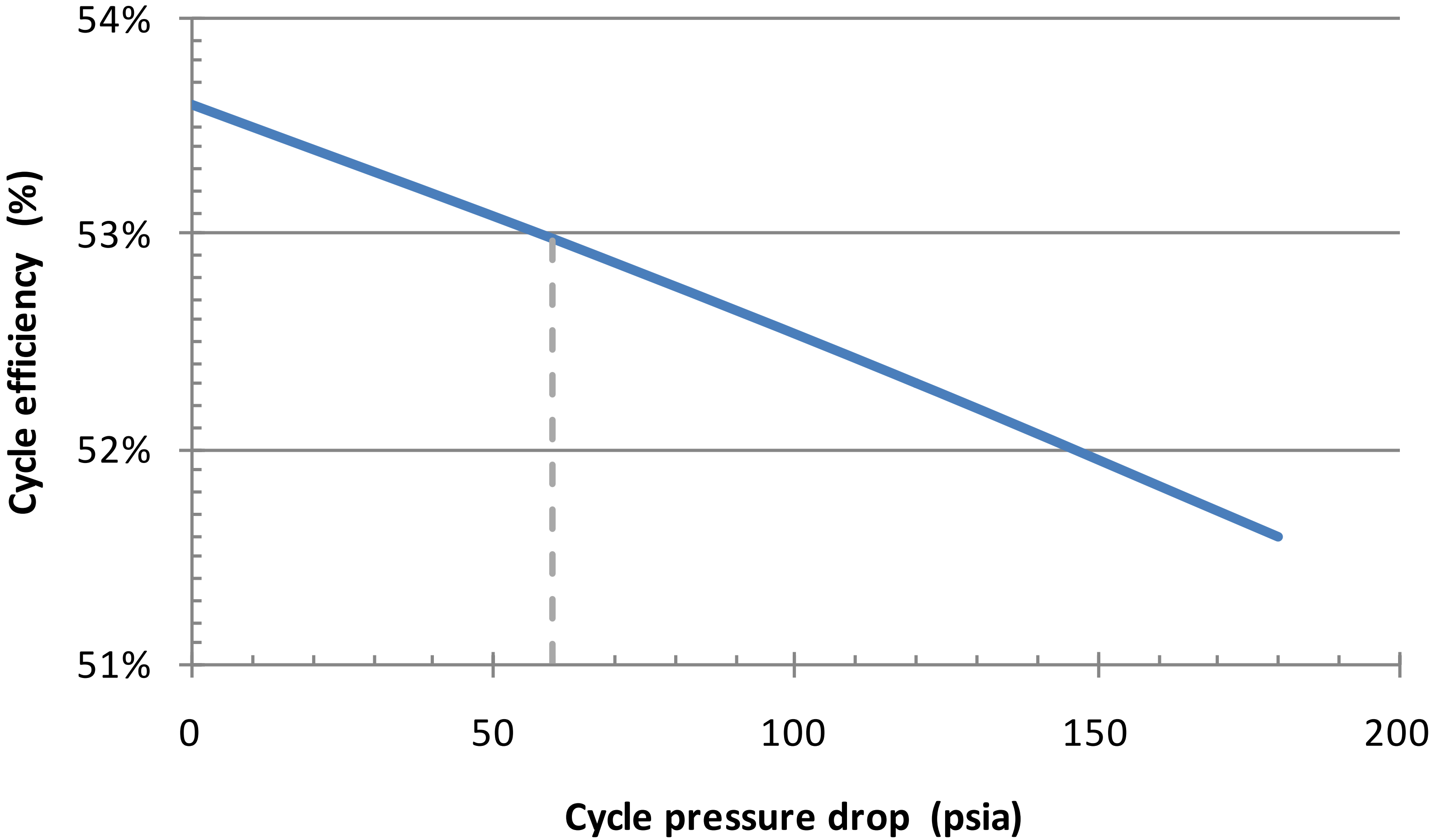
Recompression Brayton Cycle

Sensitivity to pressure drop



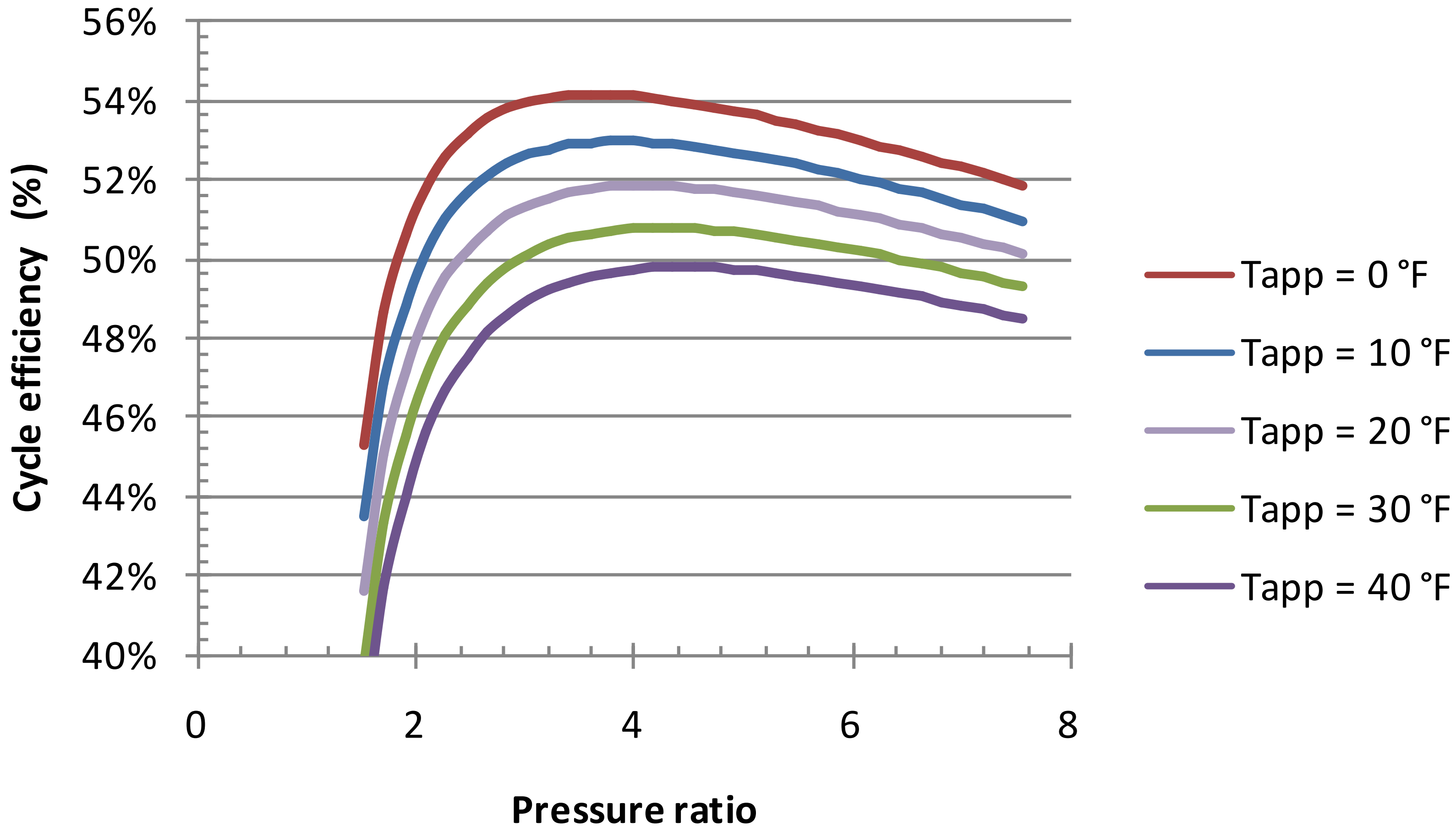
Recompression Brayton Cycle

Sensitivity to pressure drop



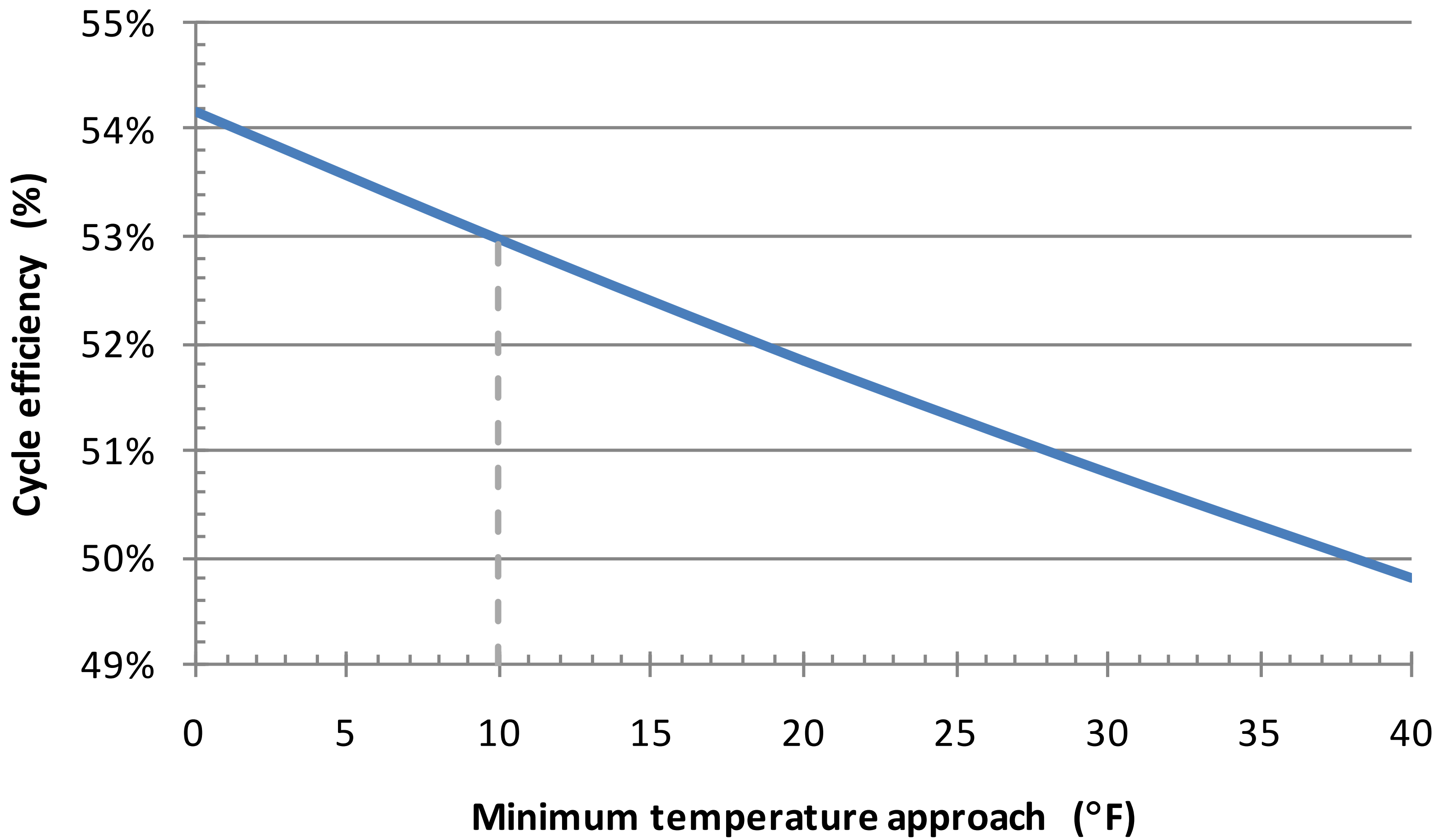
Recompression Brayton Cycle

Sensitivity to minimum temperature approach



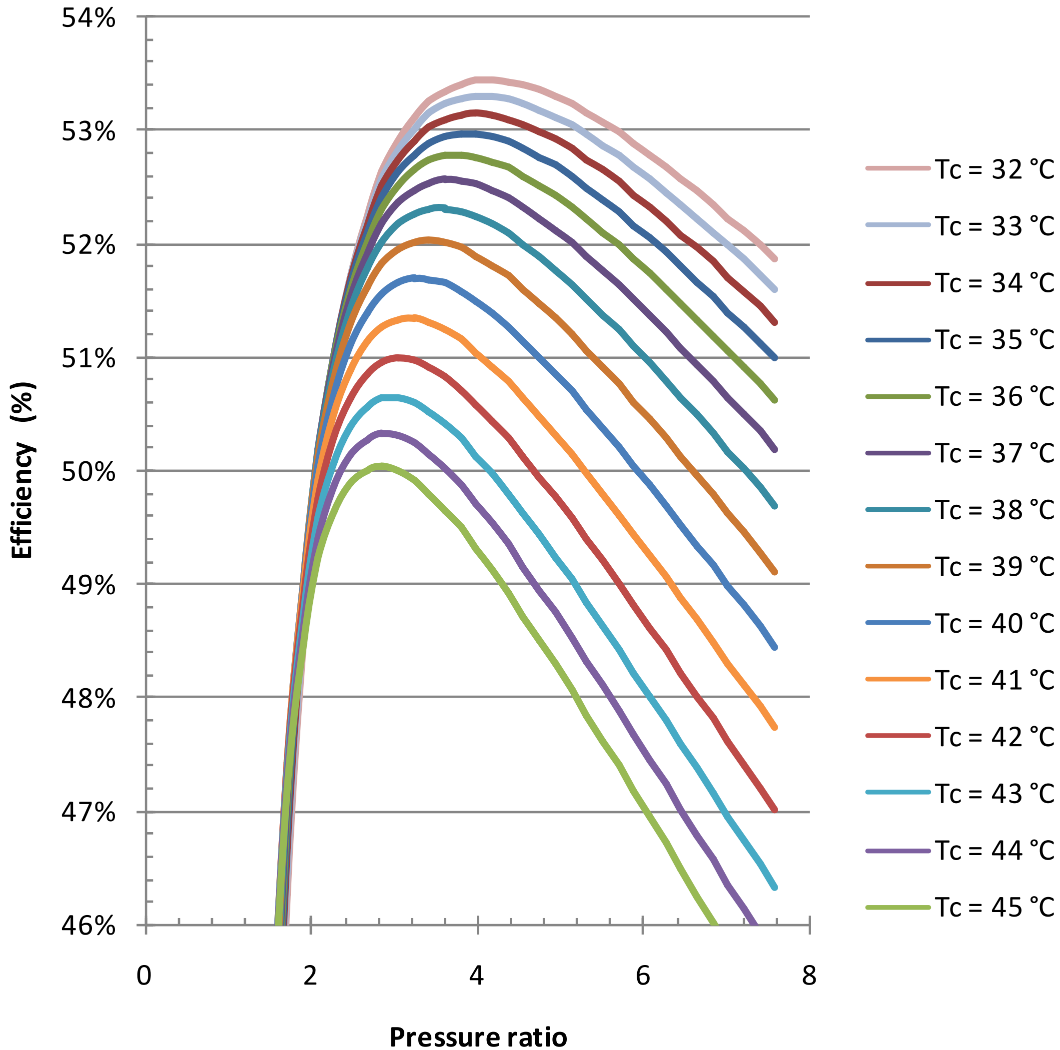
Recompression Brayton Cycle

Sensitivity to minimum temperature approach



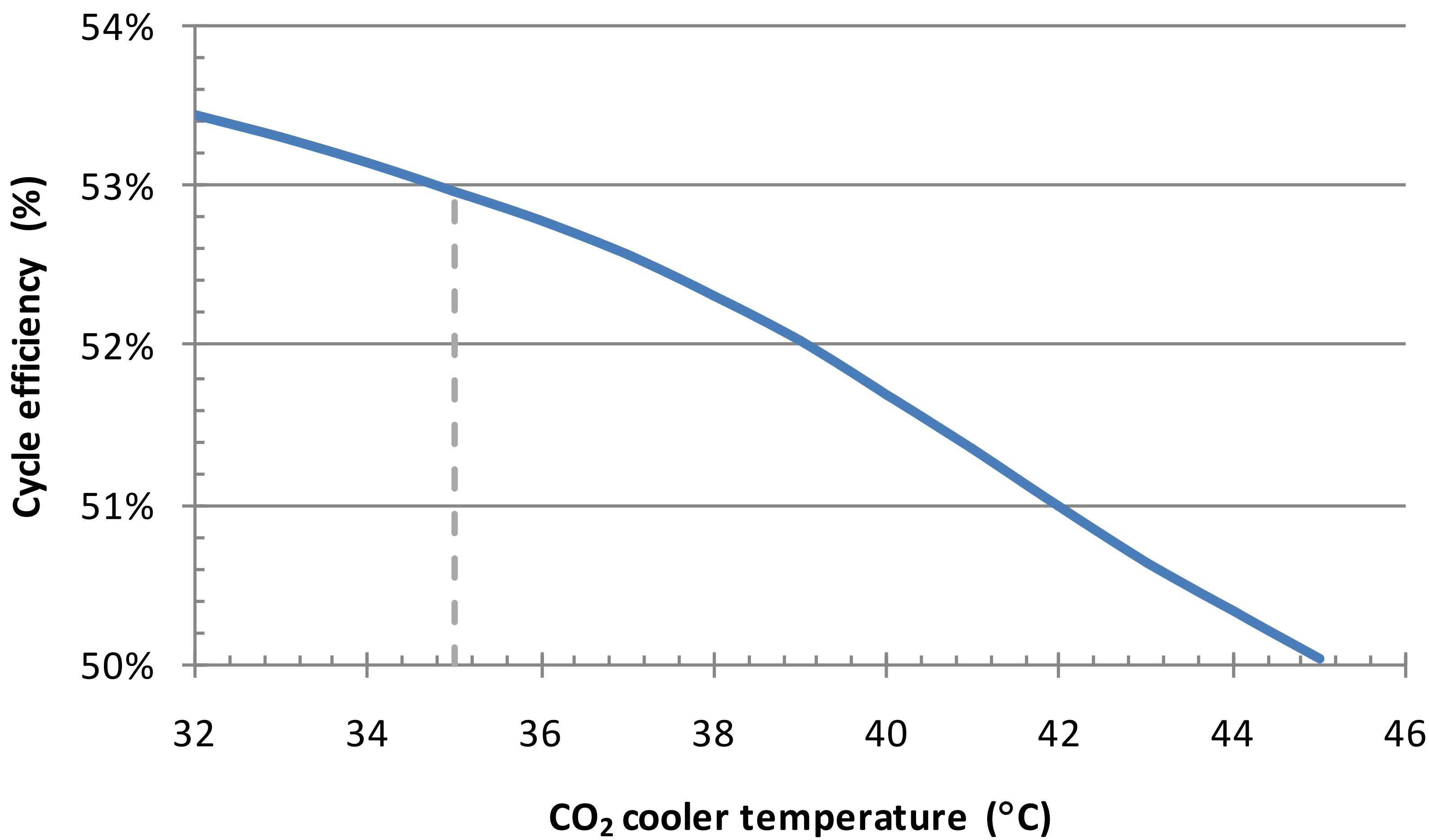
Recompression Brayton Cycle

Sensitivity to CO_2 cooler temperature



Recompression Brayton Cycle

Sensitivity to CO_2 cooler temperature



Indirect cost variables

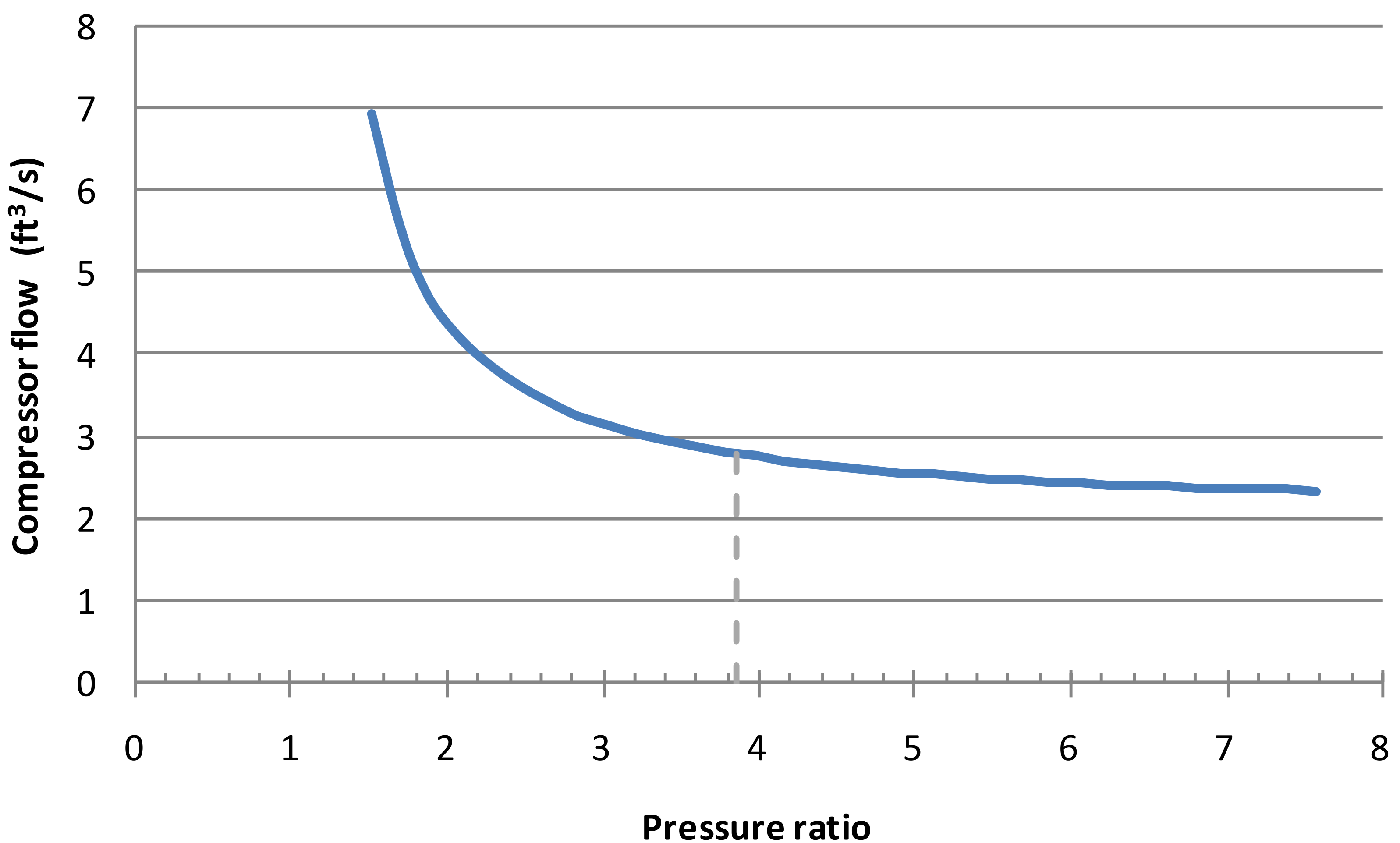
- **Provide a "surrogate" for inferring relative cost impacts**
- **Reliable costs for sCO_2 recompression Brayton cycle not available**
- **Process variables or derived quantities that have a strong influence on cost**
- **Used to determine if a cycle configuration is on a steep part of the sensitivity curve**

Indirect cost variables

Cycle component	Indirect cost metric	Comment
Overall Cycle	Temperature	Materials selection
	Pressure	Ambiguous indicator
	Cycle efficiency	Inverse operating costs
	Mass flow rate, Specific power	Indicator of overall plant size
Compressor/Turbine	Power, Mass flow	Indicator of unit size
	Pressure ratio	Number of stages required
	Inlet volumetric flow	Indicator of inlet size
Recuperator	Total heat duty, LMTD (UA)	Indicator of unit size
Heat source	Total heat duty, LMTD (UA), CO_2 thermal capacitance	Indicator of unit size

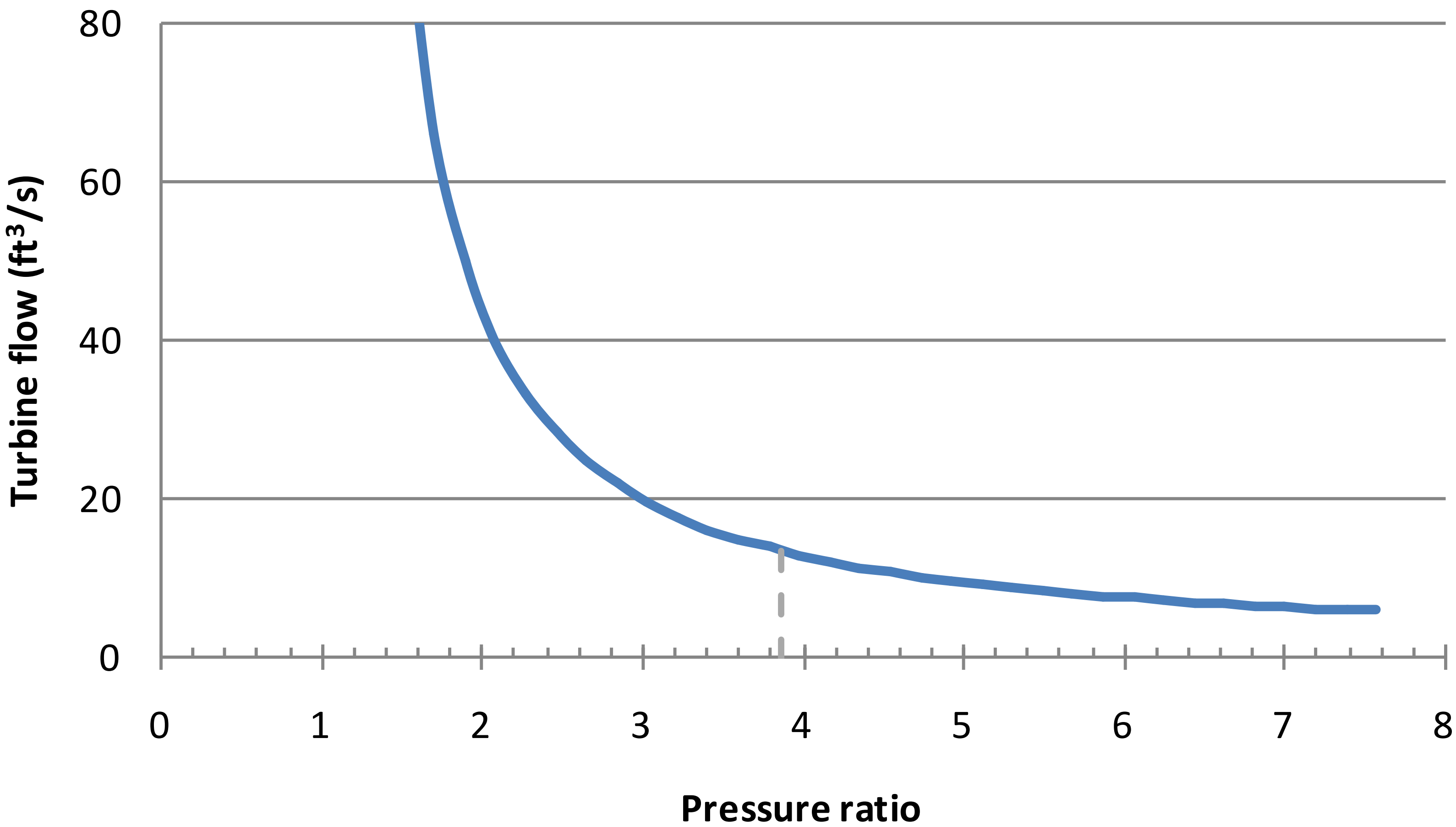
Recompression Brayton Cycle

Main compressor inlet volumetric flow



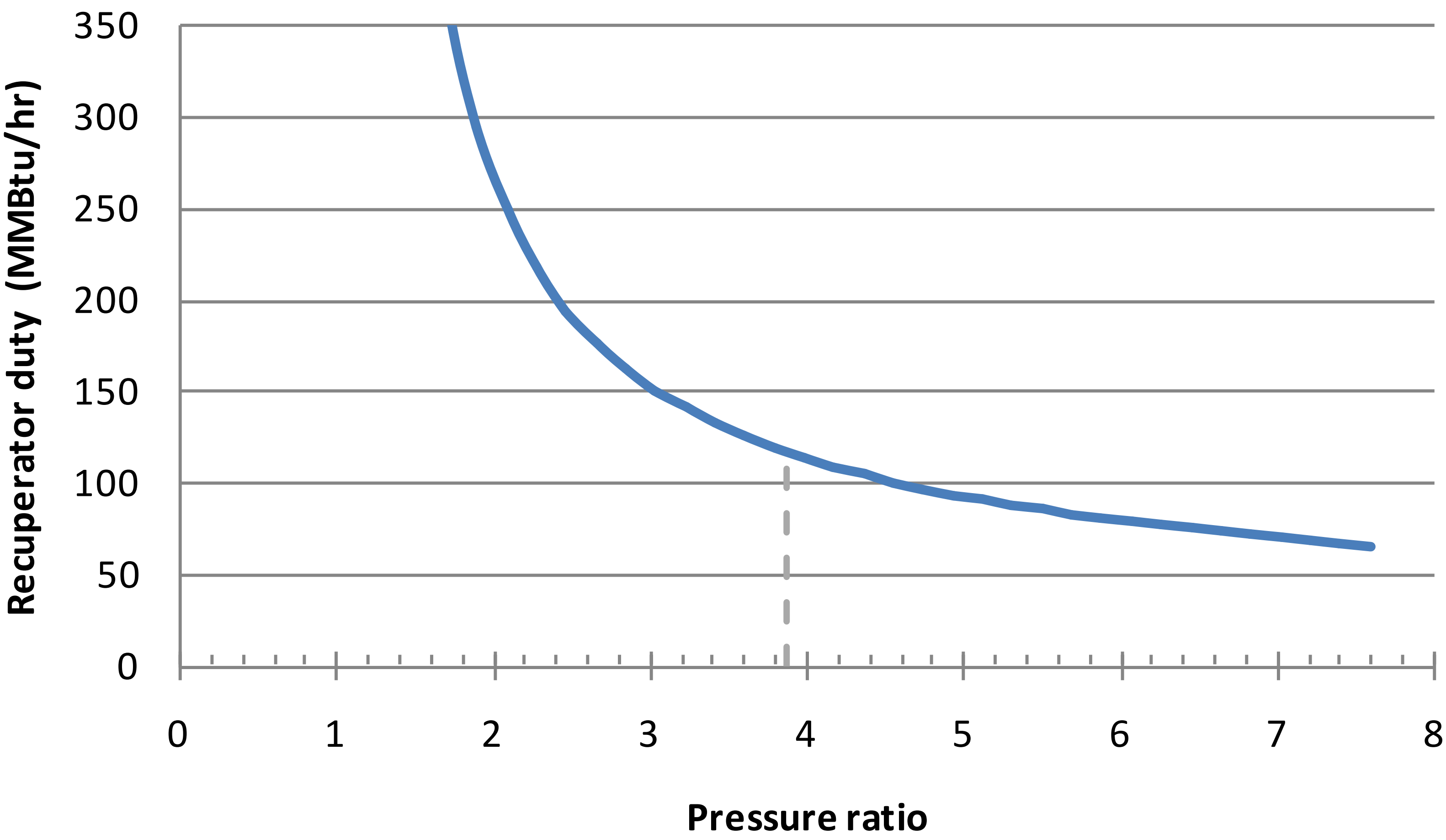
Recompression Brayton Cycle

Turbine inlet volumetric flow



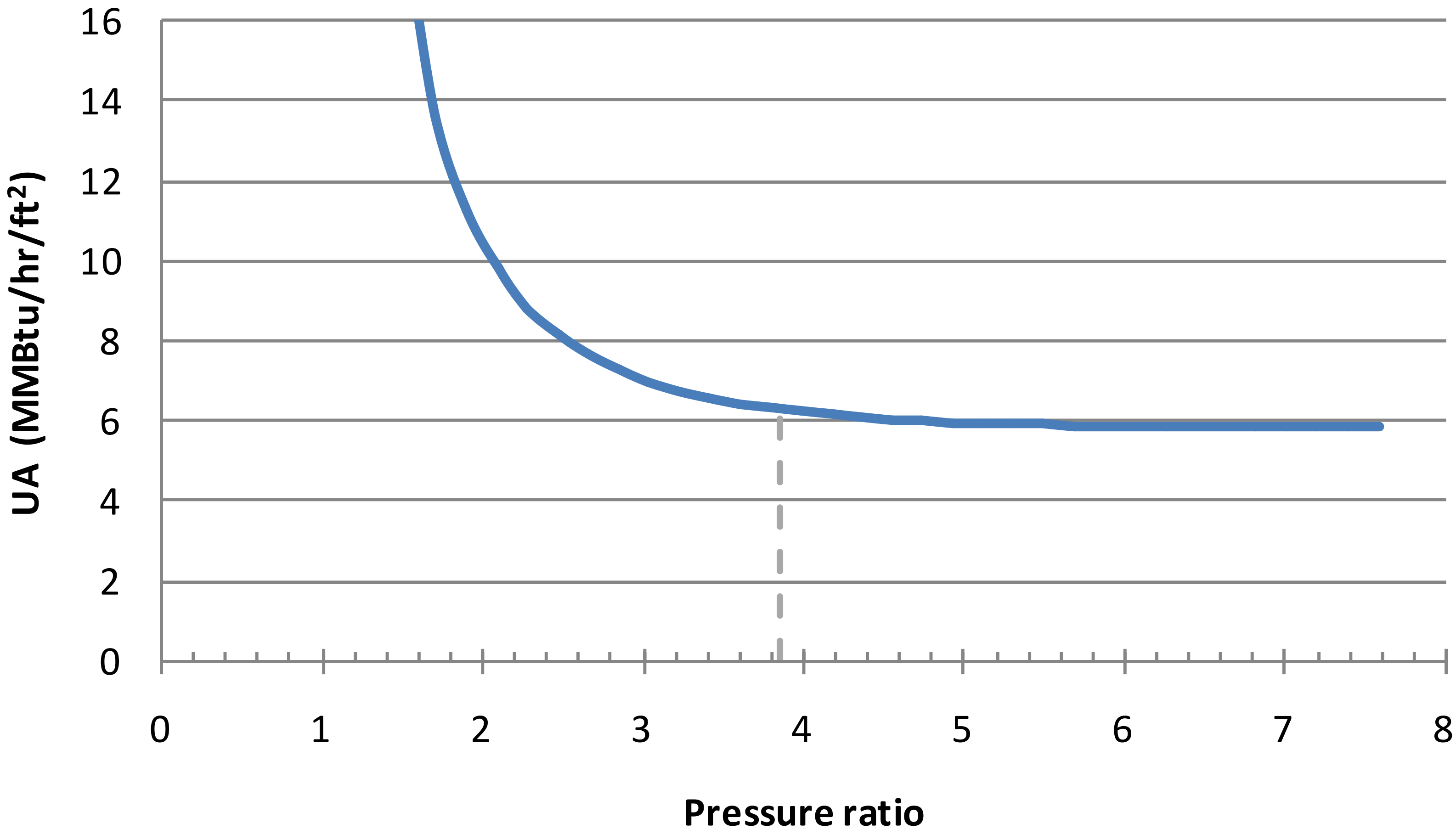
Recompression Brayton Cycle

Total recuperator duty



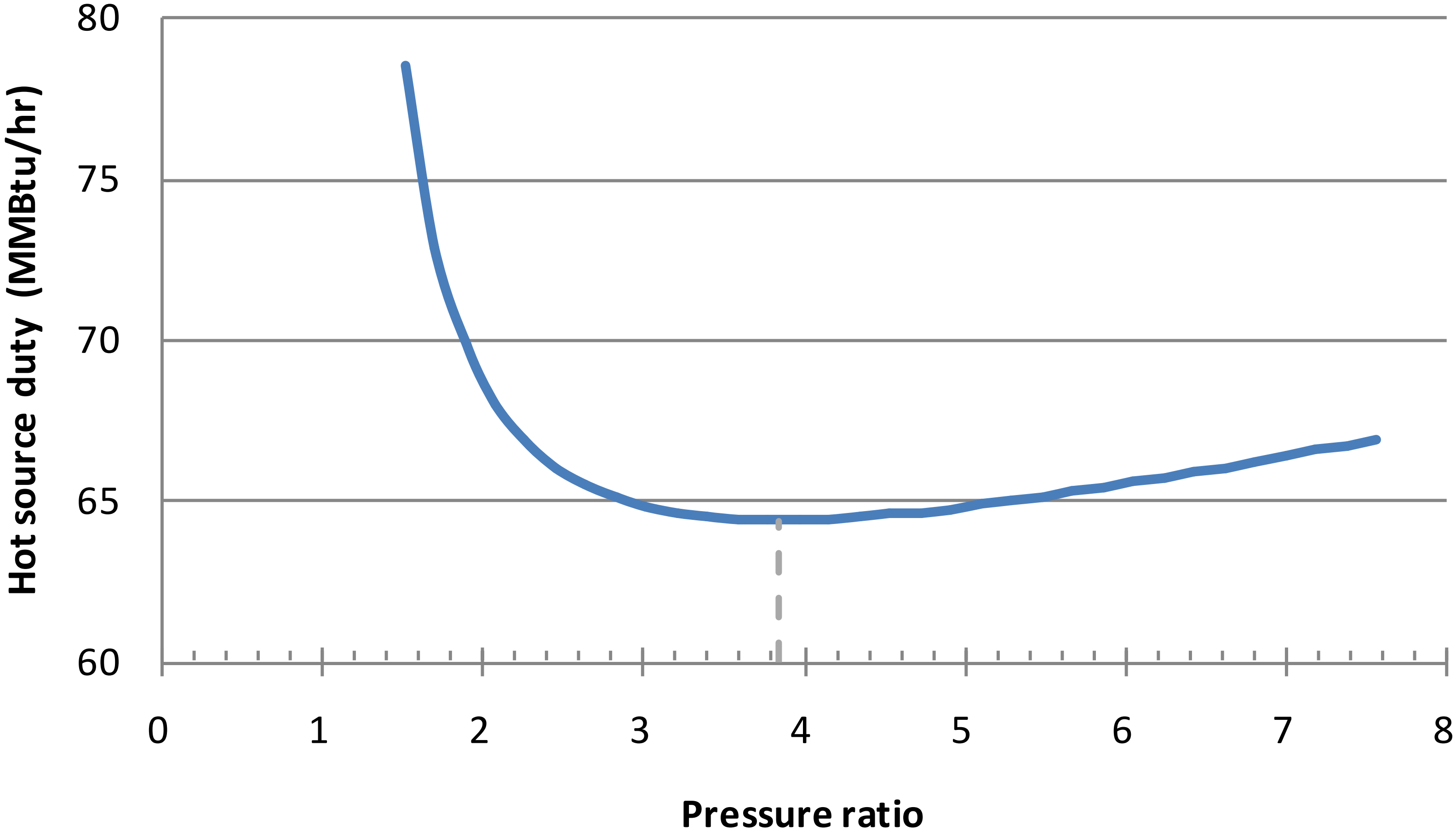
Recompression Brayton Cycle

Total recuperator UA



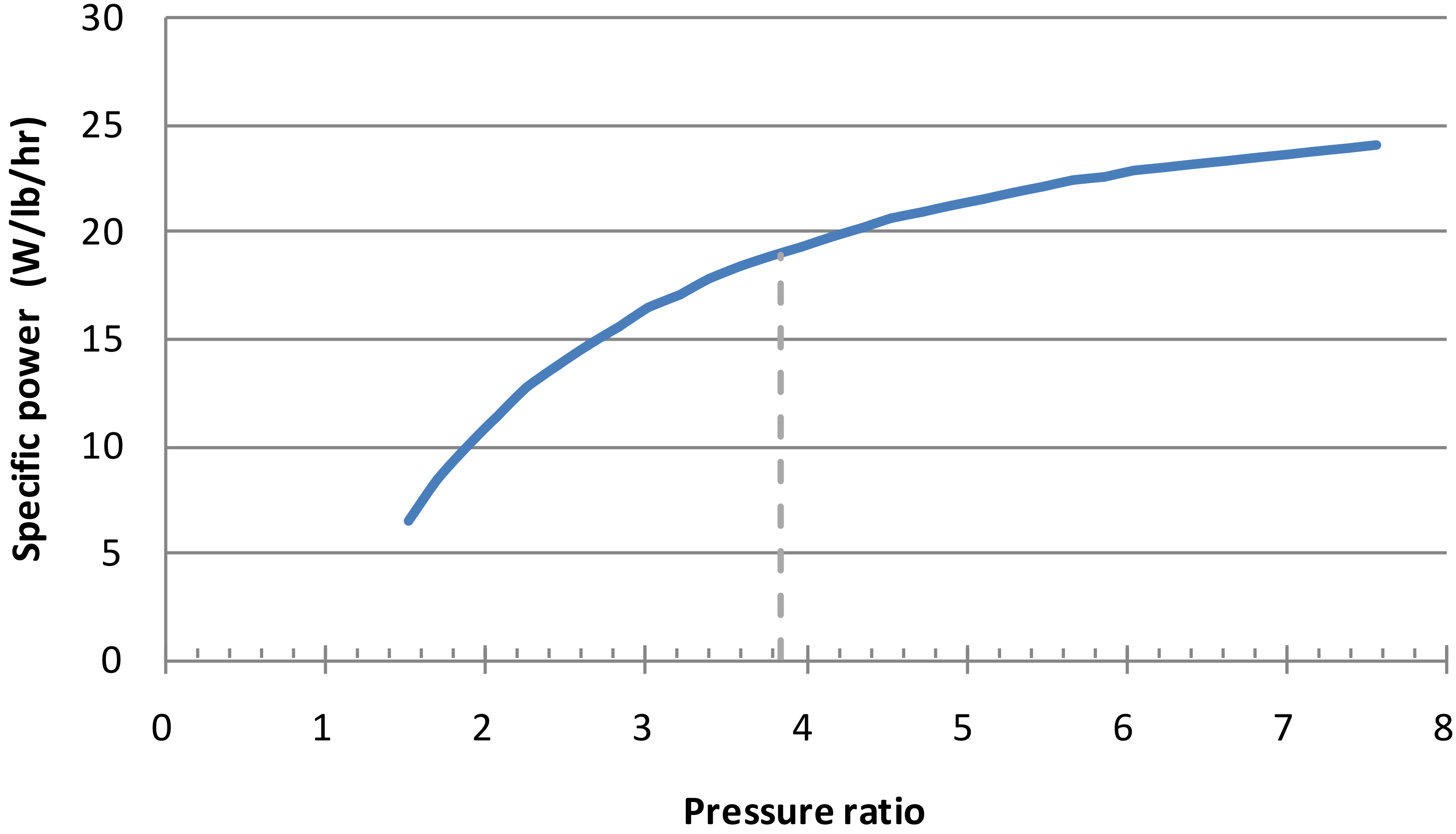
Recompression Brayton Cycle

Hot source duty



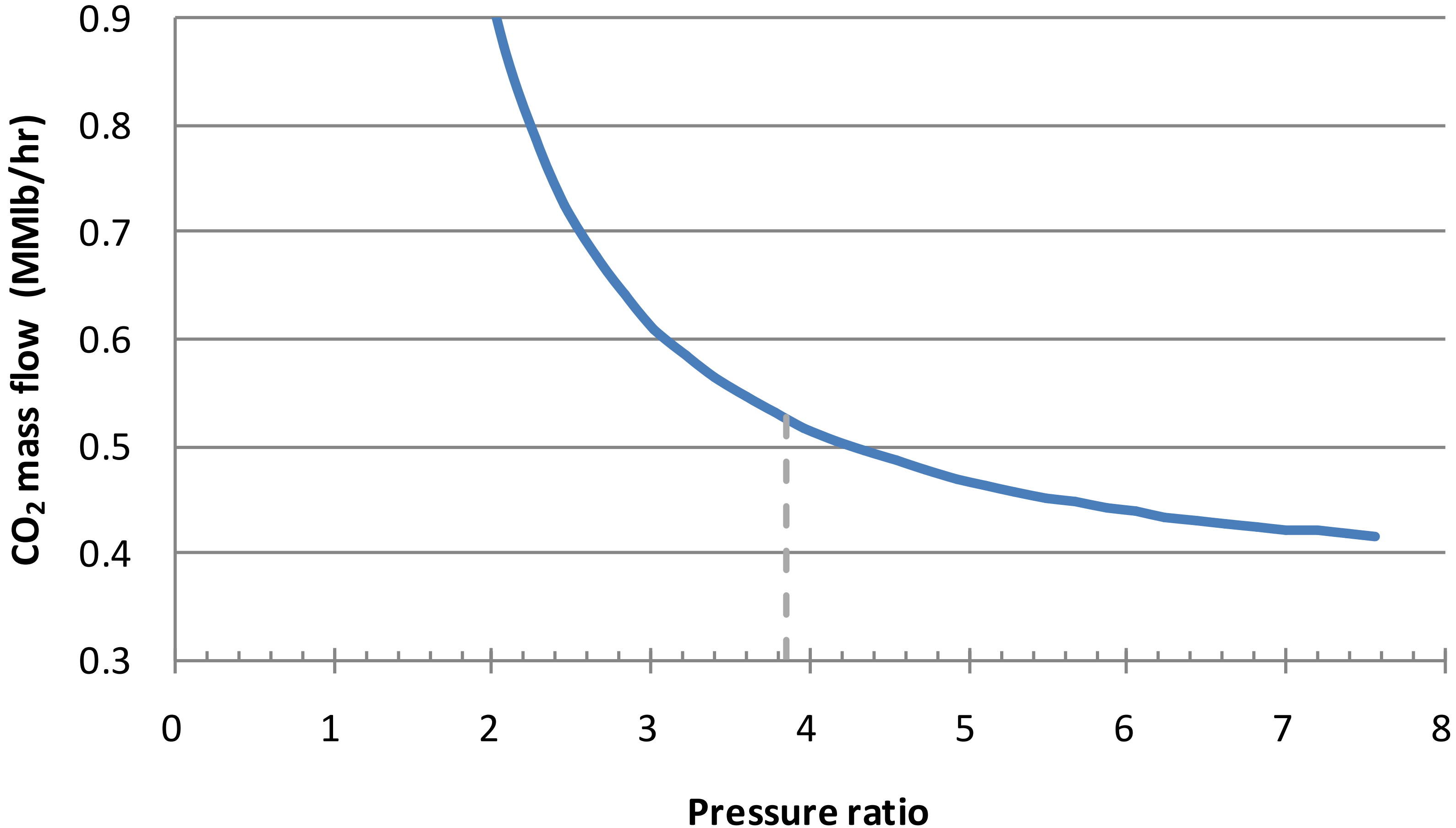
Recompression Brayton Cycle

Specific power



Recompression Brayton Cycle

CO_2 flow



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Summary

- **sCO_2 recompression Brayton cycles appear to offer a number of benefits including high cycle efficiency**
- **The baseline cycle operating parameters offer a relatively high efficiency operation**
- **Non-ideal properties of CO_2 near the critical region make the recompression cycle advantageous**

Summary

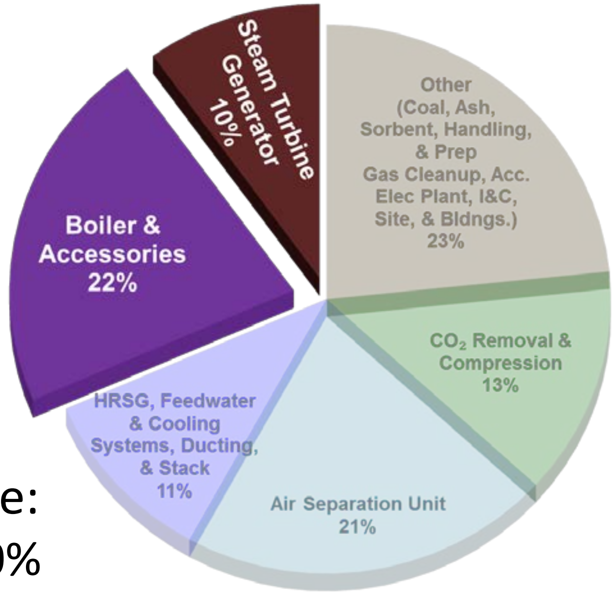
- Care must be taken to assure that cycle operation is not unduly sensitive to perturbations

- Sensitivity studies suggest the cycle may offer benefits in a wide variety of applications and settings

- The baseline cycle operating parameters do not appear to be in a region of pronounced cost sensitivity

SCO_2 Power Cycles for Coal-Based Power Plants

- **Applicable to multiple coal-based platforms (air and oxygen-fired, PC, CFB, PFBC)**
  - Coal combustor modifications (and associated costs) needed to accommodate SCO_2 heating and to match temperature-enthalpy profile of SCO_2 cycles of interest



- **Efficiency improvements afforded by SCO_2 power cycles have the potential to substantially reduce the cost of electricity (COE) of coal-based systems:**
  - Increase in efficiency reduces fuel costs and base plant capital costs per MW of output
  - If combustor + power island costs = steam cycle:
    ↑ 5 efficiency percentage pts => ↓ COE by >10%
  - For a breakeven COE:
    ↑ 1 efficiency percentage pt allows for ↑ 12% in combustor + power island costs relative to steam cycle