A Comparative Study of Heat Rejection Systems for sCO_2 Power Cycles

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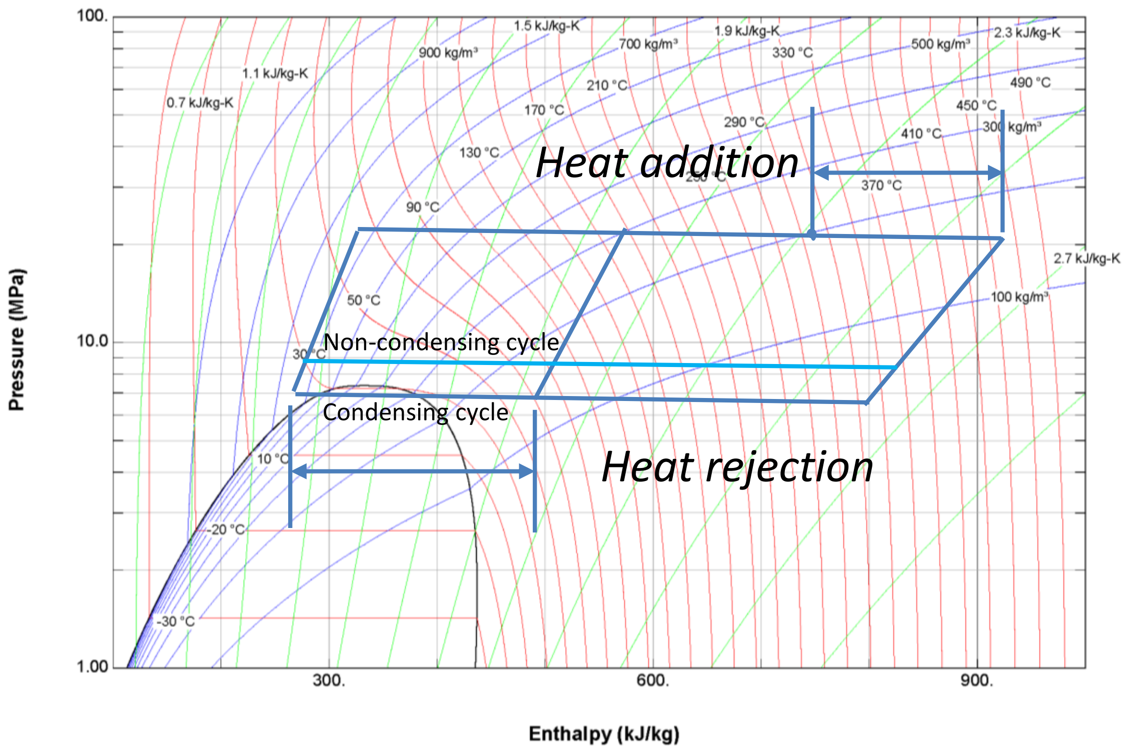
ECHOGEN
power systems

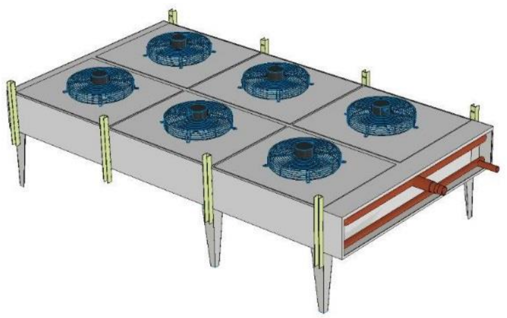
Heat rejection systems

- Common to all closed-loop cycles, sCO_2 systems need to reject residual heat

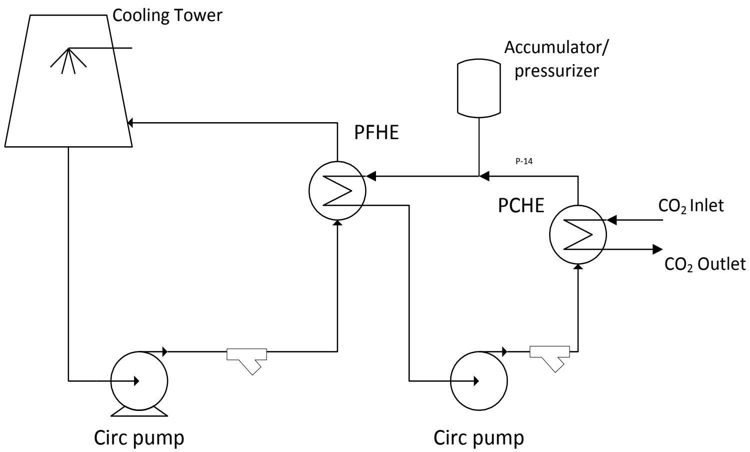


Heat rejection technology

- Air cooled
  - Fin-fan cooler
  - Low air-side dP (< 2”wc)
  - Aux loads = fan drives

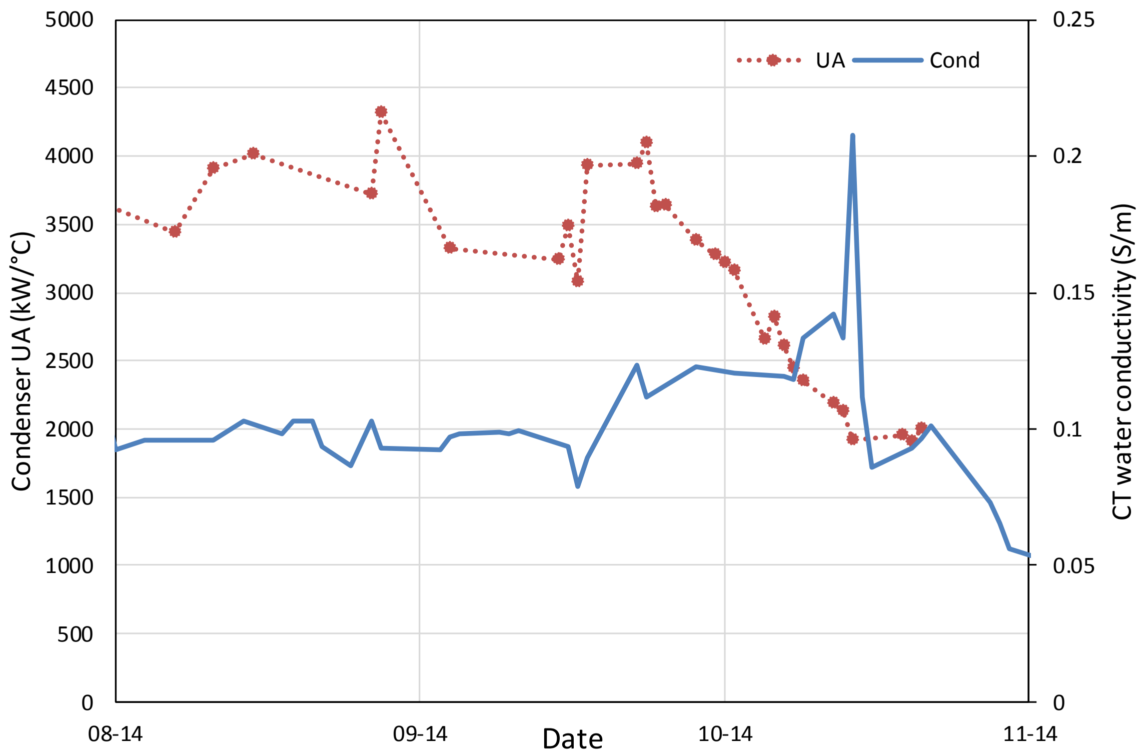


- Water-cooled
  - Cooling tower (forced draft)
  - Intermediate water-loop required for PCHE CO_2-water HX
  - Aux loads = fan drives + pumps



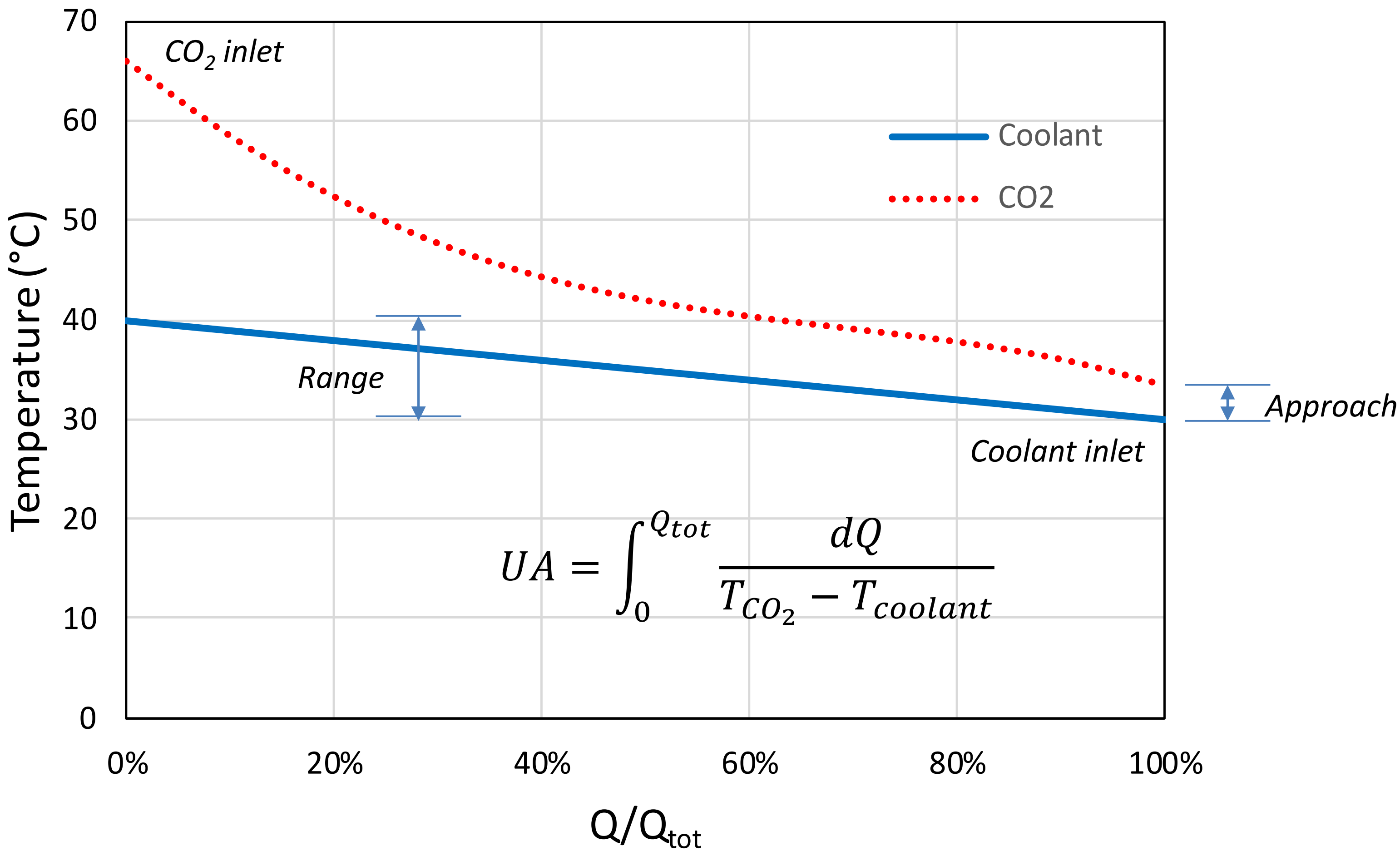
- Hybrid solutions exist (WSAC, ACC with fogging) – not considered for this paper

Why you should not use direct CT water feed to your PCHE



a) The manufacturer advises against it
b) Very small change in water conductivity resulted in significant PCHE performance loss

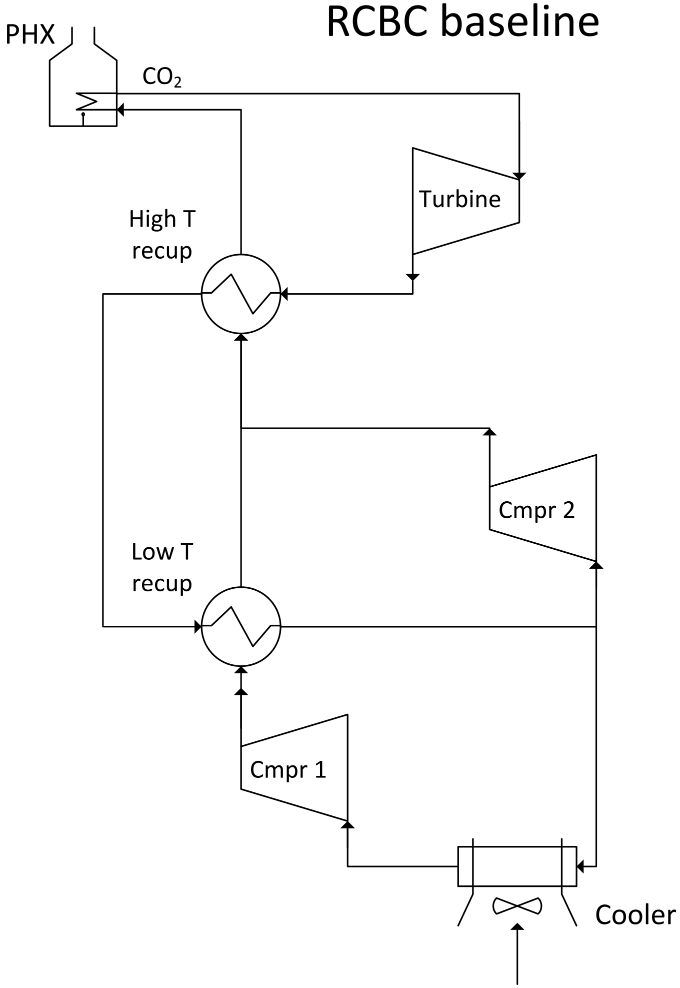
Condenser performance & nomenclature

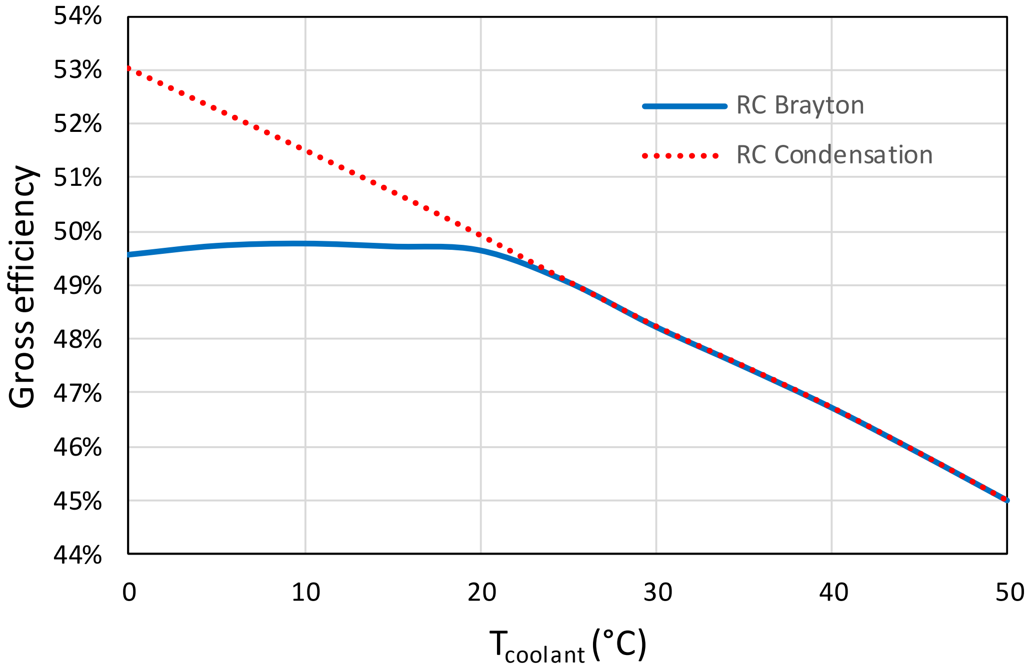


$$UA = \int_0^{Q_{tot}} \frac{dQ}{T_{CO_2} - T_{coolant}}$$

Cycle performance

RCBC baseline



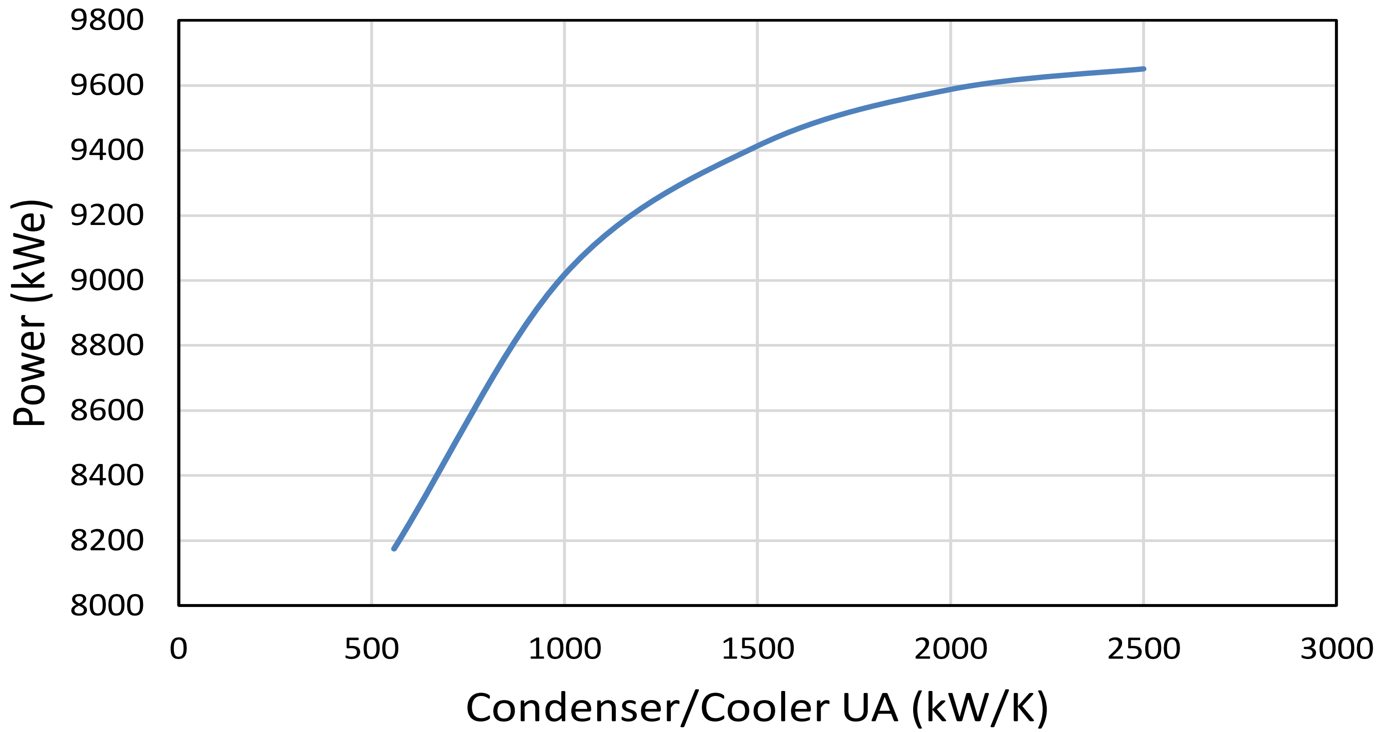


Notes:

Gross efficiency does not include coolant aux load

Cycle performance plotted as function of *coolant* T

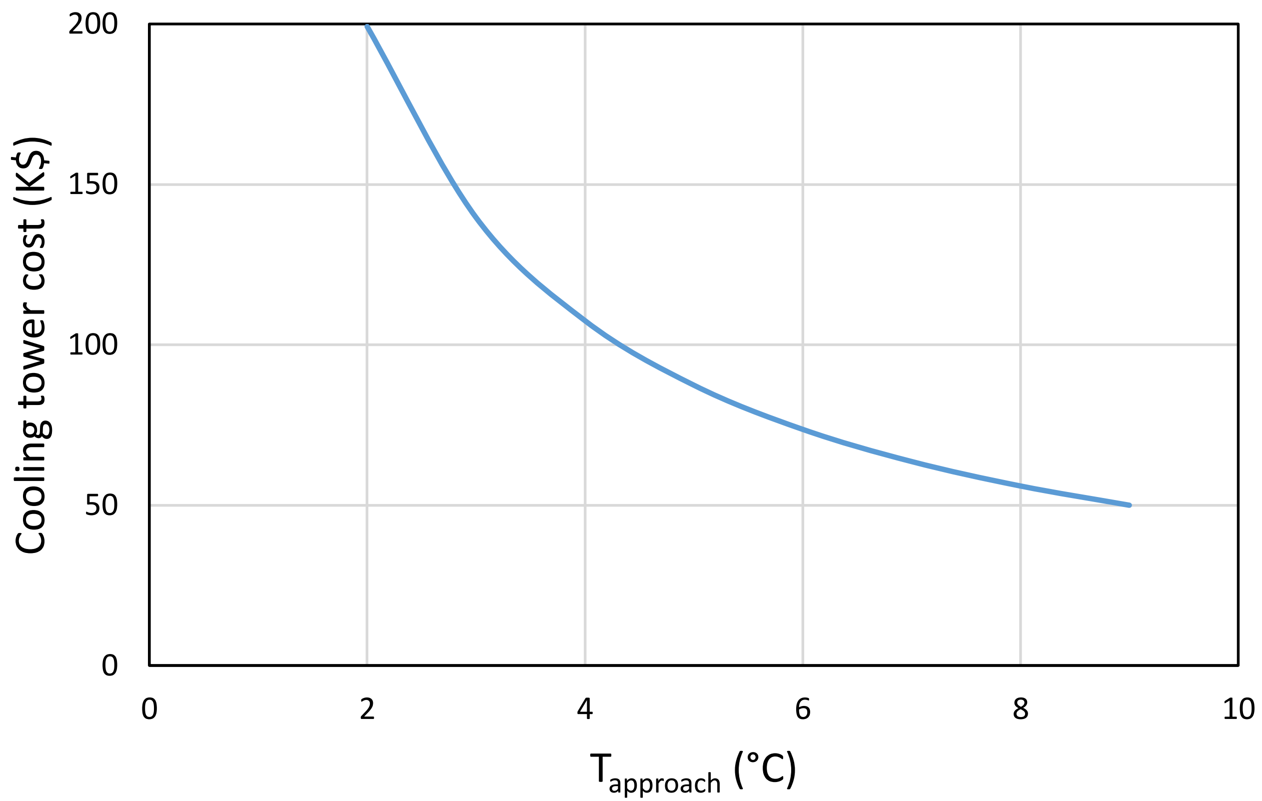
Heat exchanger sizing



Cost generally proportional to UA

Design value = 1500 kW/°C (both water & air)

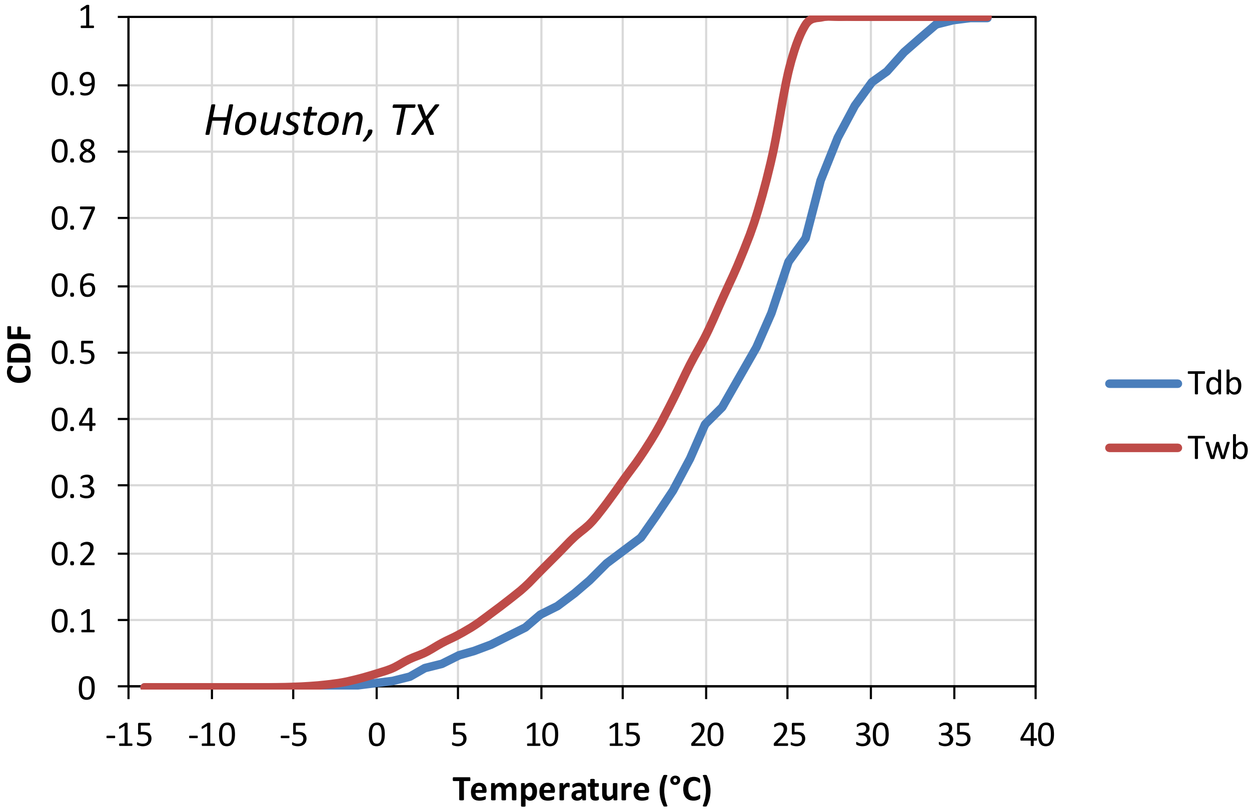
Cooling tower sizing



Cost function of design approach temperature

3°C regarded as a practical minimum by CT suppliers, used for this study

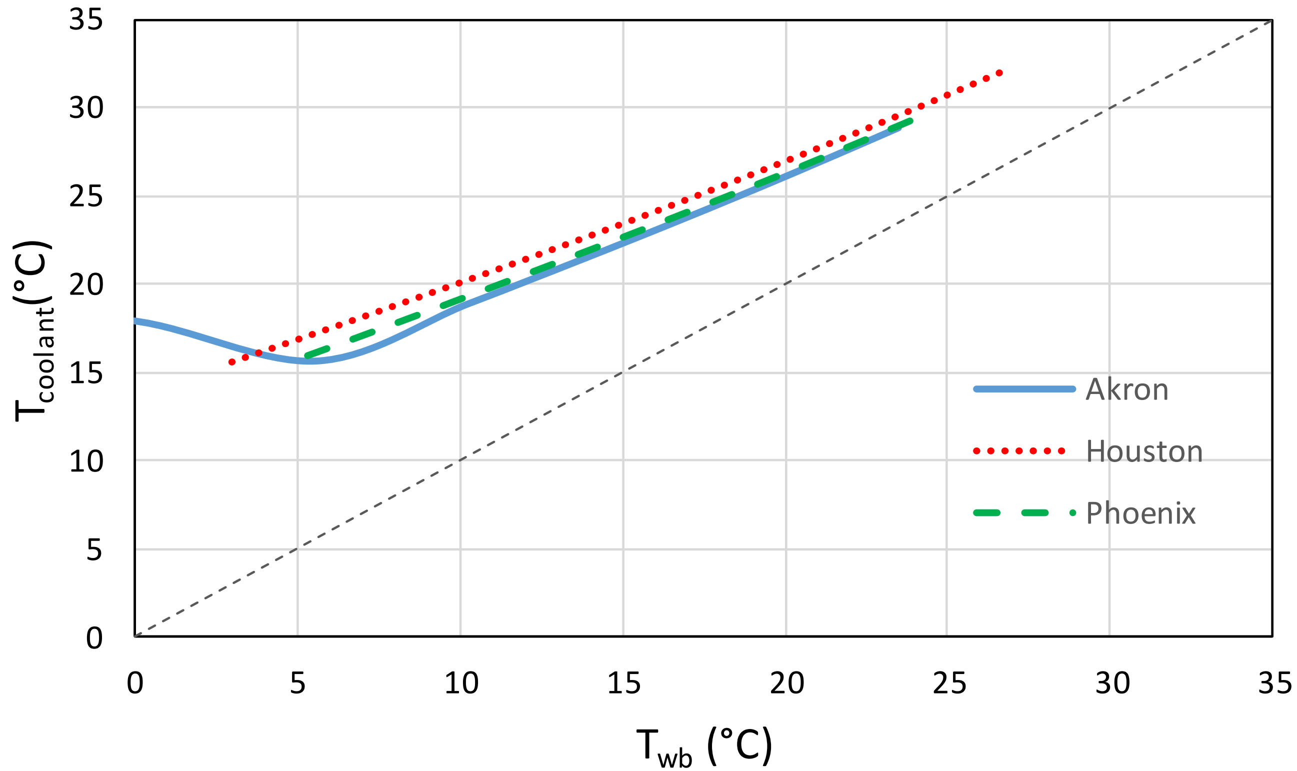
Local climate impacts



Hourly observations from 2014 converted to CDF format

T_{wb} affects water (evaporative) cooling, T_{db} affects air cooling

Cooling tower performance as f($T_{ambient}$)

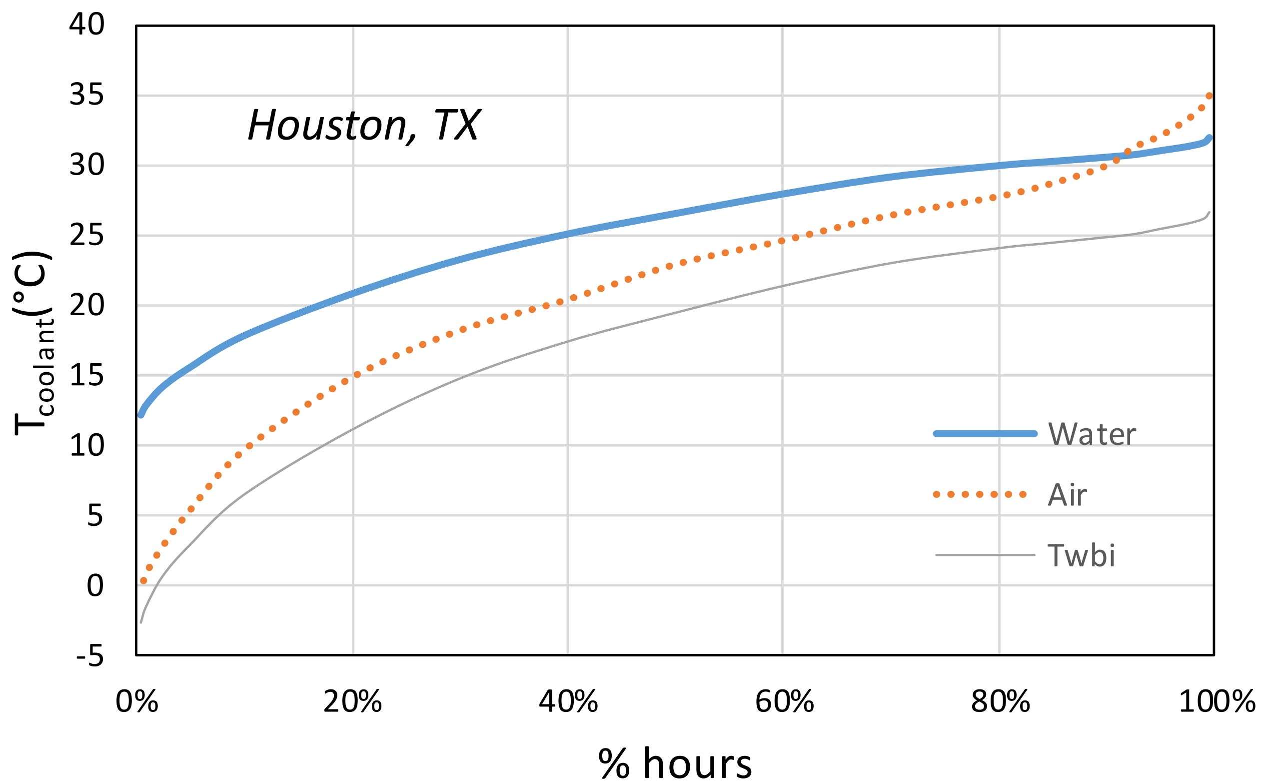


20°C selected as design point

Demin water loop adds another 3°C to approach temperature

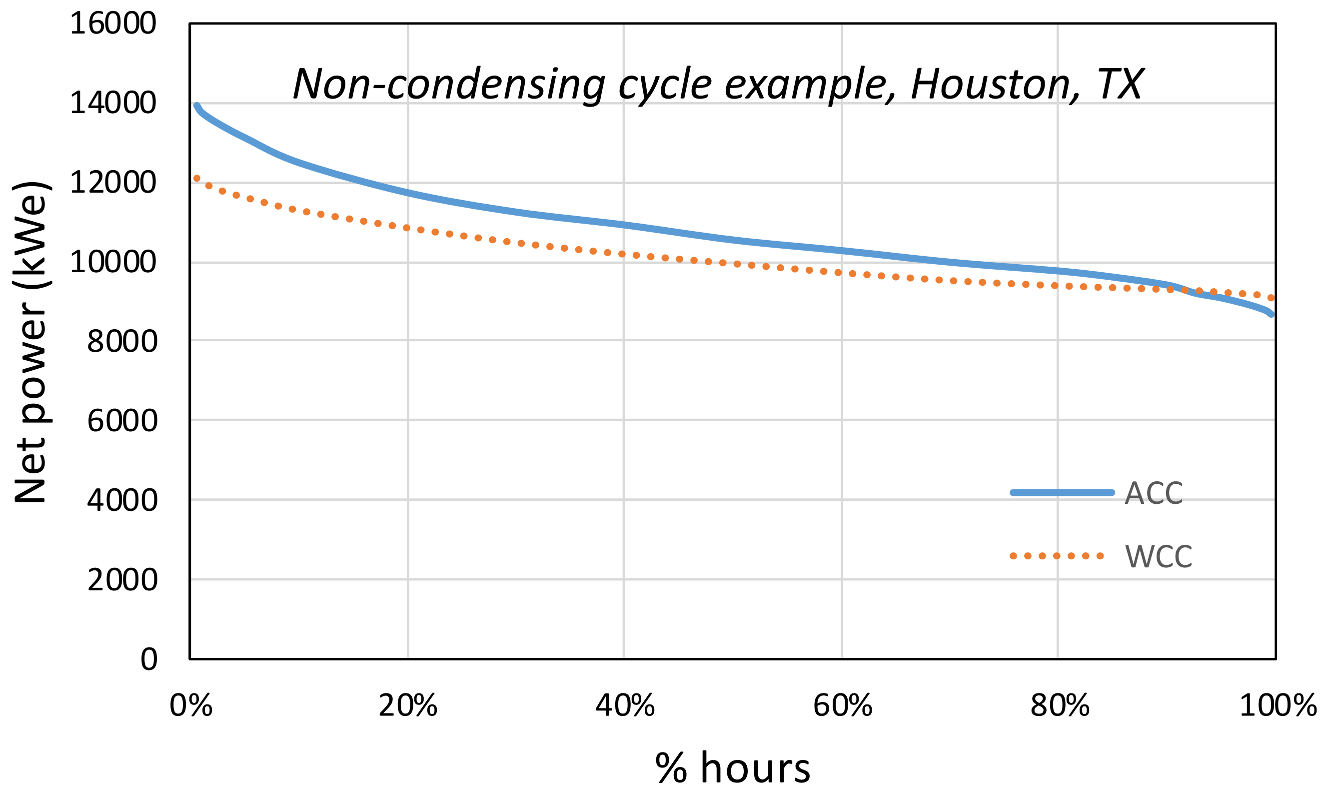
As Twb approaches 0°C, water T increases to avoid freezing

Coolant temperature distribution



Coolant temperature CDF calculated as function of wet/dry bulb temperature CDFs

Cycle performance over 1-year period

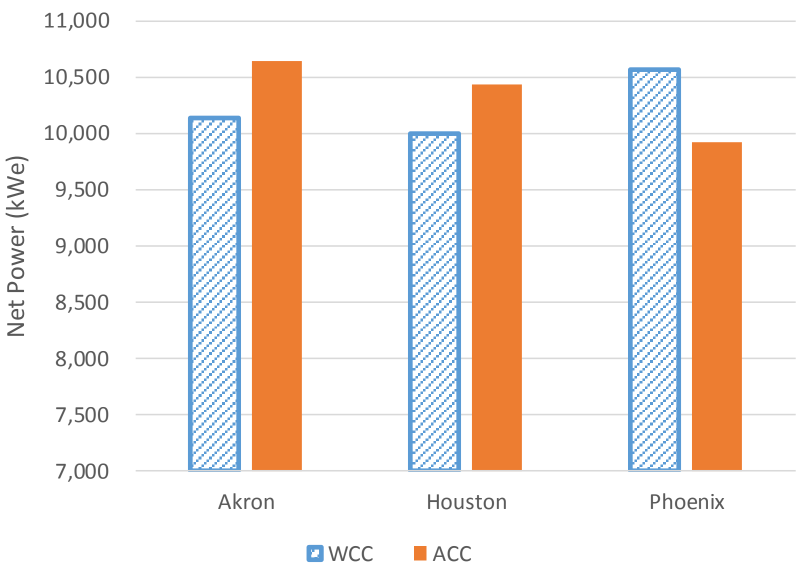


Coolant CDFs convolved with Power = f($T_{coolant}$) to calculated CDF of net power

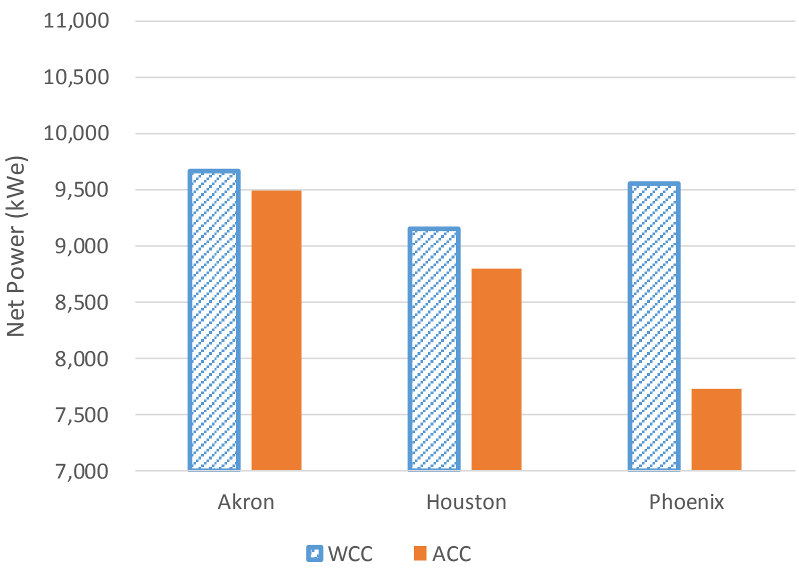
Results integrated to yield annualized average power

Net power output (non-condensing cycle)

Annualized average



99% hot day



ACC outperforms on average

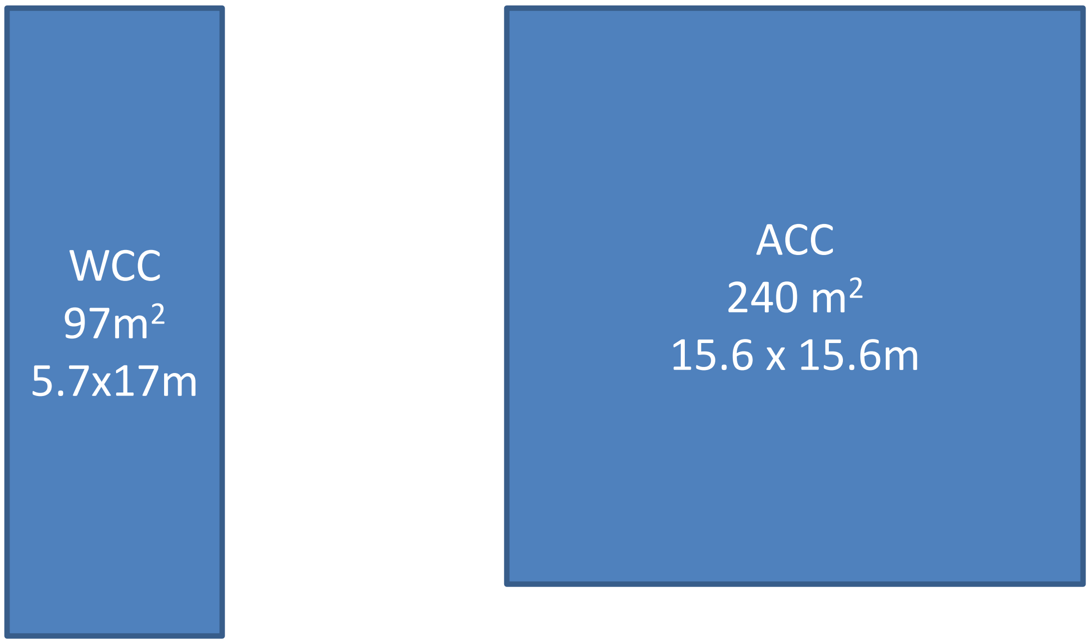
Hot-day performance falloff ~ 2-4% for non-arid climates

Auxiliary load comparison

Load	WCC	ACC
Fans	46	310
CW pump	99	
PFHE pump	112	
Total	257	310

Lower cooling tower fan loads largely offset by increased pump loads

Footprint comparison



Cooling tower footprint smaller than ACC, does not include space for pumps, water treatment, etc.

Capital cost comparison

	WCC	ACC
Cooling tower/ACC	$ 143,000	$ 695,000
Water treatment	$ 20,000	
CT Pumps	$ 44,000	
CT/ACC Piping	$ 41,000	$ 108,000
PFHE	$ 83,000	
PFHE Pumps	$ 46,000	
PFHE Piping	$ 16,000	
Filters	$ 5,000	
WCC PCHE	$ 300,000	
Total eqpt	$ 698,000	$ 803,000
Installation	$ 419,000	$ 482,000
Total	$ 1,117,000	$ 1,285,000

ACC slightly (15%) higher

O&M cost comparison (annual)

	WCC	ACC
Water consumption	$ 156,000	
Water disposal	$ 57,000	
Water treatment	$ 25,000	
Chemical replacement	$ 65,000	
Pump maintenance	$ 24,000	
Fan maintenance	$ 7,500	$ 30,000
Maintenance cost/yr	$ 334,500	$ 30,000
$/kWh	$ 0.0042	$ 0.0004

Significantly lower O&M costs, largely driven by elimination of water supply, treatment and disposal costs

Reduced O&M pays back increased capex of ACC in << 1 year

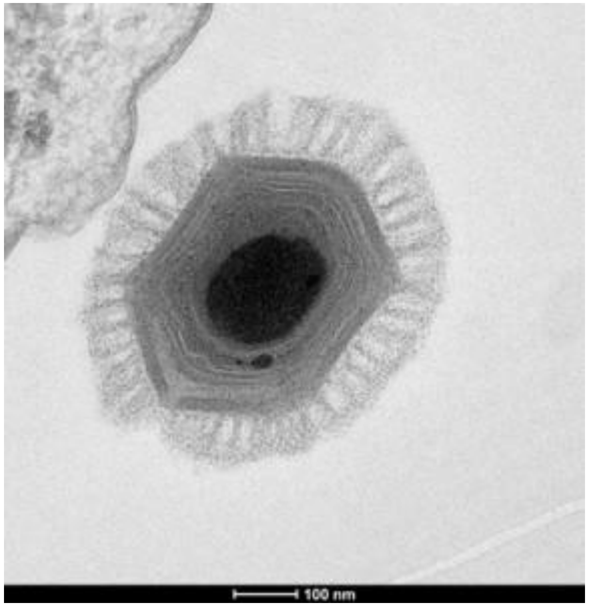
Other reasons to prefer ACC

Cooling water filter cleaning is … unpleasant

Other reasons to prefer ACC

Cold-weather operation is even less pleasant

Other reasons to prefer ACC



“Mimivirus” – world’s largest virus, discovered in a UK cooling tower

Legionella bacterium – often found in cooling towers. Infects 10,000-18,000 people per year in the US alone

Cooling towers are excellent industrial-scale Petri dishes

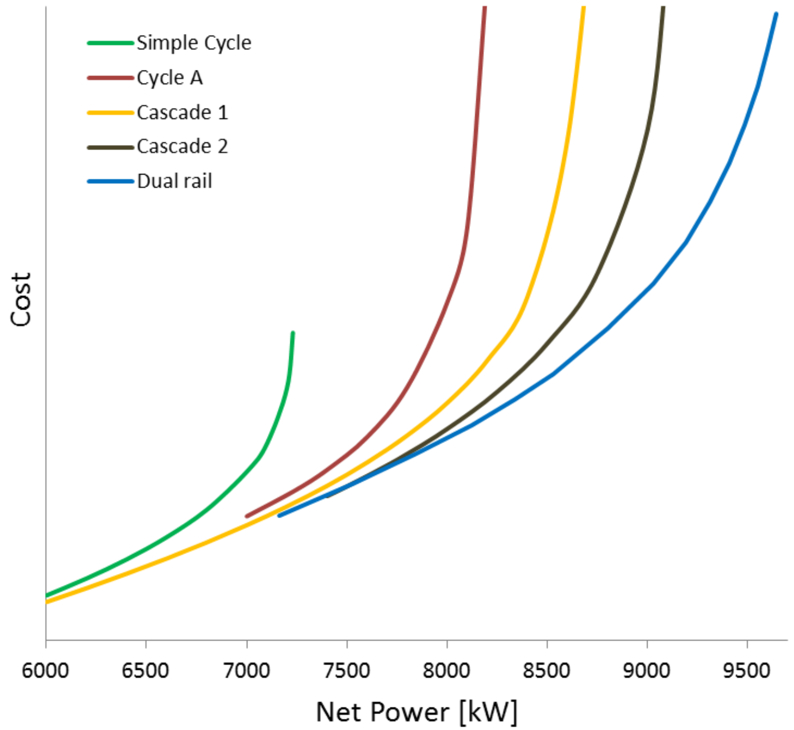
Conclusions

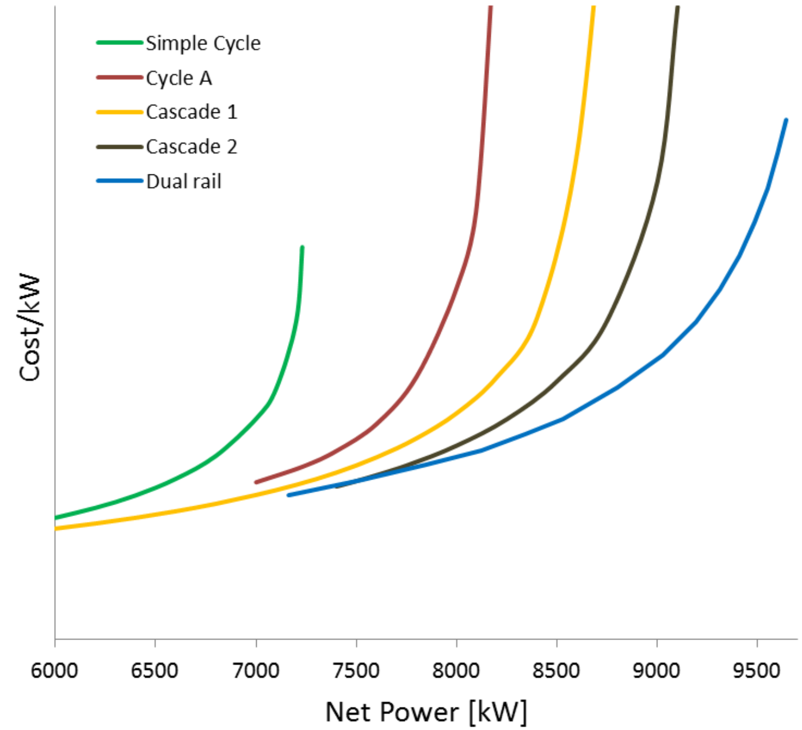
- Water cooling advantages
  - Better performance on hot days, especially in arid climates
  - Smaller footprint
- Air cooling advantages
  - Better annualized average power output except in arid climates (where water cooling is impractical anyway)
  - Lower O&M costs
  - Simpler operation
  - Near zero water consumption for sCO_2 power cycles
- Costs and auxiliary loads are similar

Air cooling nearly always the better choice

Backup slides

Cycle / cost modeling

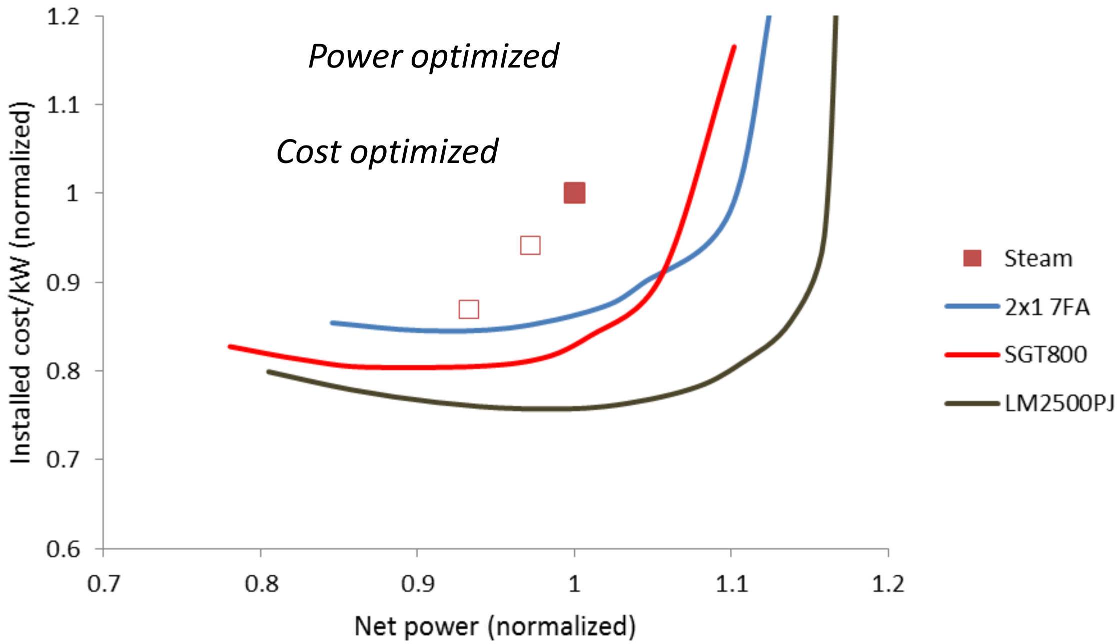




- Optimization process defines cycle with minimum cost for given power output
- Multiple solutions generates curves of cost vs power
- Allows selection of optimal cycle architecture

Held, T.J., 2015. Supercritical CO_2 Cycles for Gas Turbine Combined Cycle Power Plants. *Power Gen International*.

sCO_2 vs steam



- Normalized to steam power & cost from GT-Pro, "power-optimized" solutions ("cost-optimized" point shown for reference)
- Same exhaust and boundary conditions used for sCO_2
- 10-20% lower cost for same power
- 7-14% higher power for same cost