Preliminary Benefits of Supercritical CO_2 (SCO_2) Power Cycles

Workshop on SCO_2 Brayton Cycle Energy Conversion R&D

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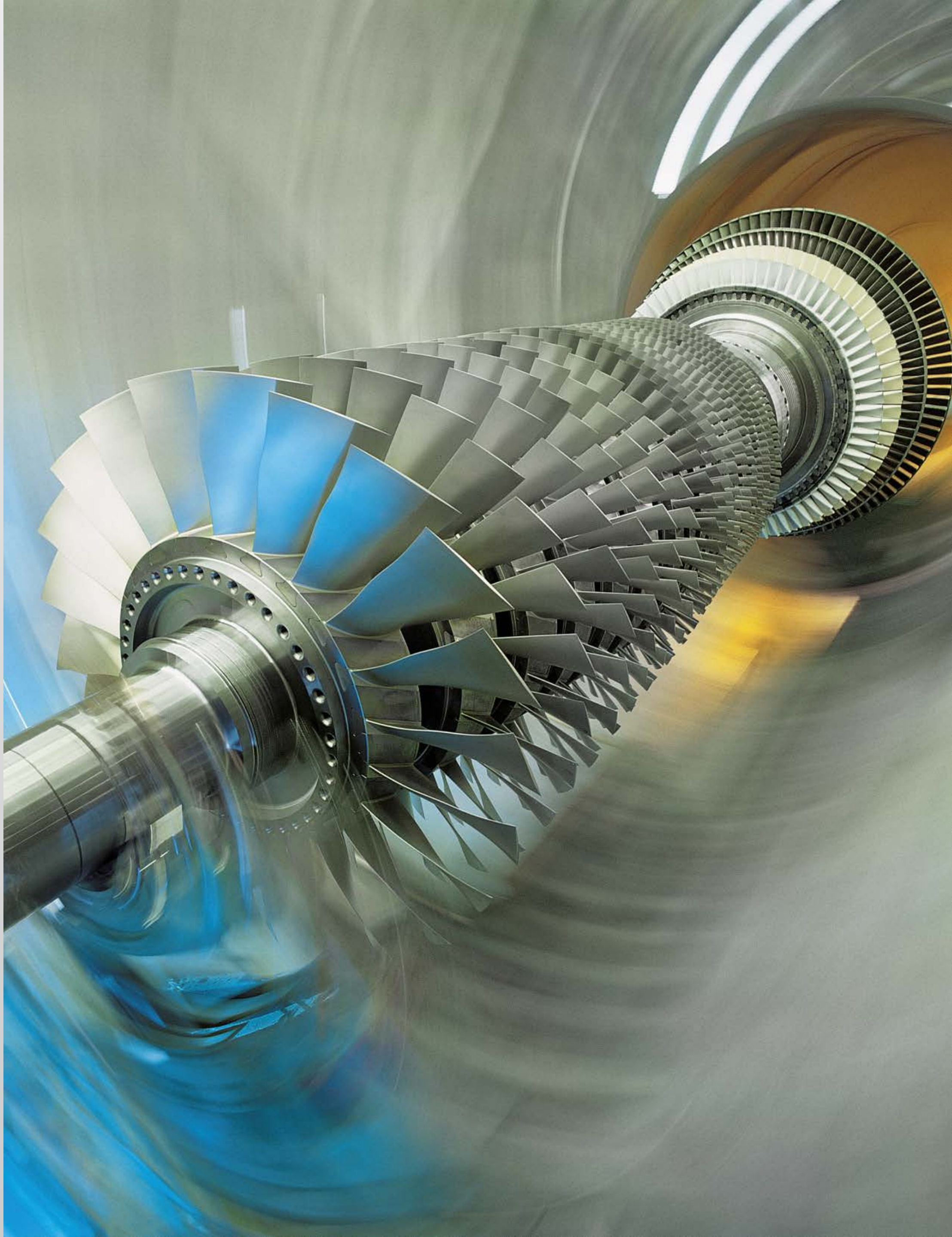

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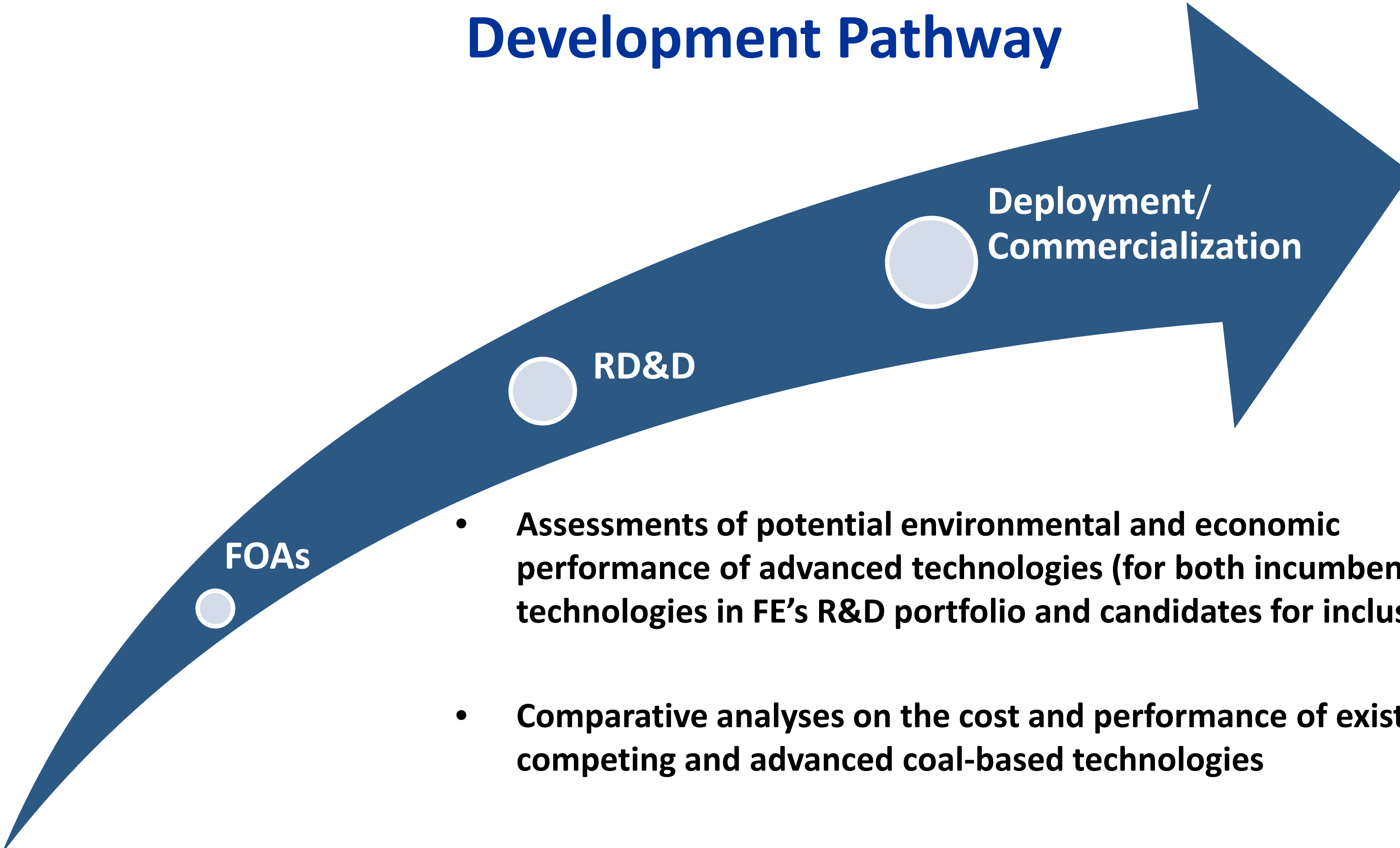
NETL's Office of Program and Performance in the Strategic Center for Coal Supports Full Technology Development Pathway

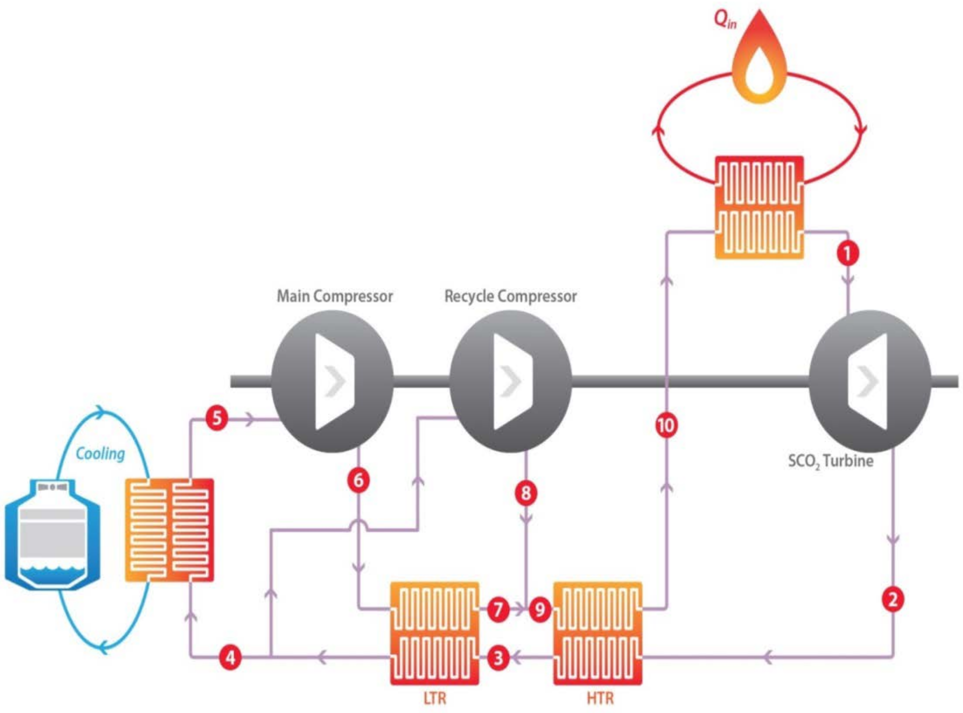


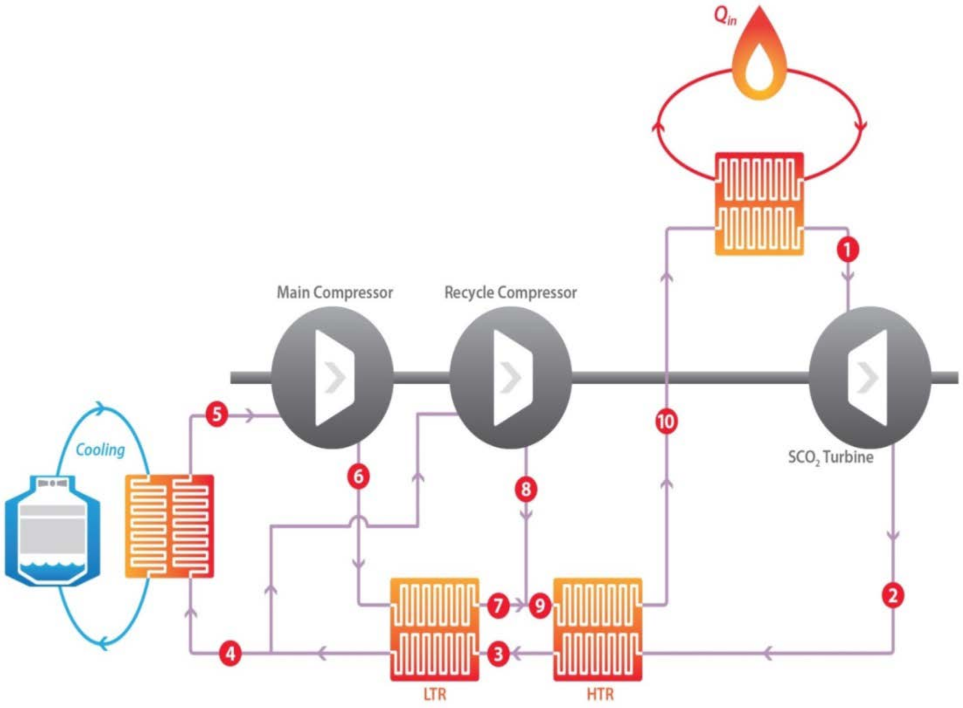
- Assessments of potential environmental and economic performance of advanced technologies (for both incumbent technologies in FE's R&D portfolio and candidates for inclusion)
- Comparative analyses on the cost and performance of existing, competing and advanced coal-based technologies
- Scenario-based forecasts of advanced technology deployment and associated societal benefits (economic, environmental and security)

FOA = Funding Opportunity Announcement

Preliminary Benefits of SCO_2 Power Cycles
Outline

- **Potential plant-level benefits of SCO_2 cycles: Coal plant example**
- **Potential power sector benefits of SCO_2 cycles**





POTENTIAL PLANT-LEVEL BENEFITS FOR COAL-BASED INDIRECT SCO_2 CYCLES

Potential Benefits for Coal-Based Indirect SCO_2 Cycles: *Application and Efficiency*

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

- **Substantial efficiency improvements anticipated as shown in table below**
  - Varies based on temperature, specific cycle configuration and heat integration

Power Cycle	Net Plant HHV Efficiency Improvement • in coal plants with 90% capture • relative to SC steam cycle[1]
AUSC Steam[2] 760°C (1400°F)	**+3.5%pts**
SCO_2 650°C (1200°F)	**+3 to 5%pts**
SCO_2 760°C (1400°F)	**+5 to 8%pts**

[1]SC = Supercritical 3500 psig/1100°F/1100°F
[2]AUSC = Advanced ultrasupercritical 5000 psig/1400°F/1400°F consistent with program targets

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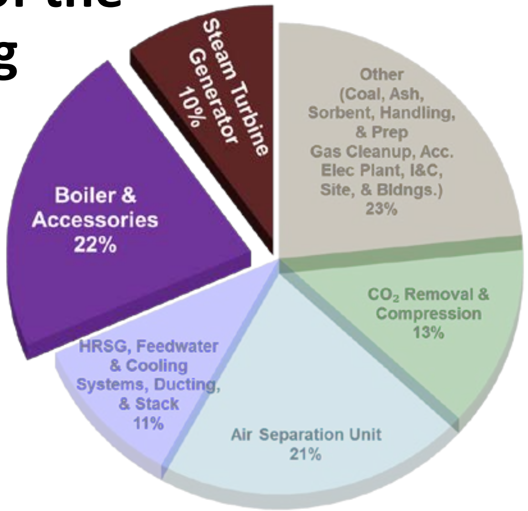
Coal-Based Supercritical CO_2 Cycles
Cost Uncertainties

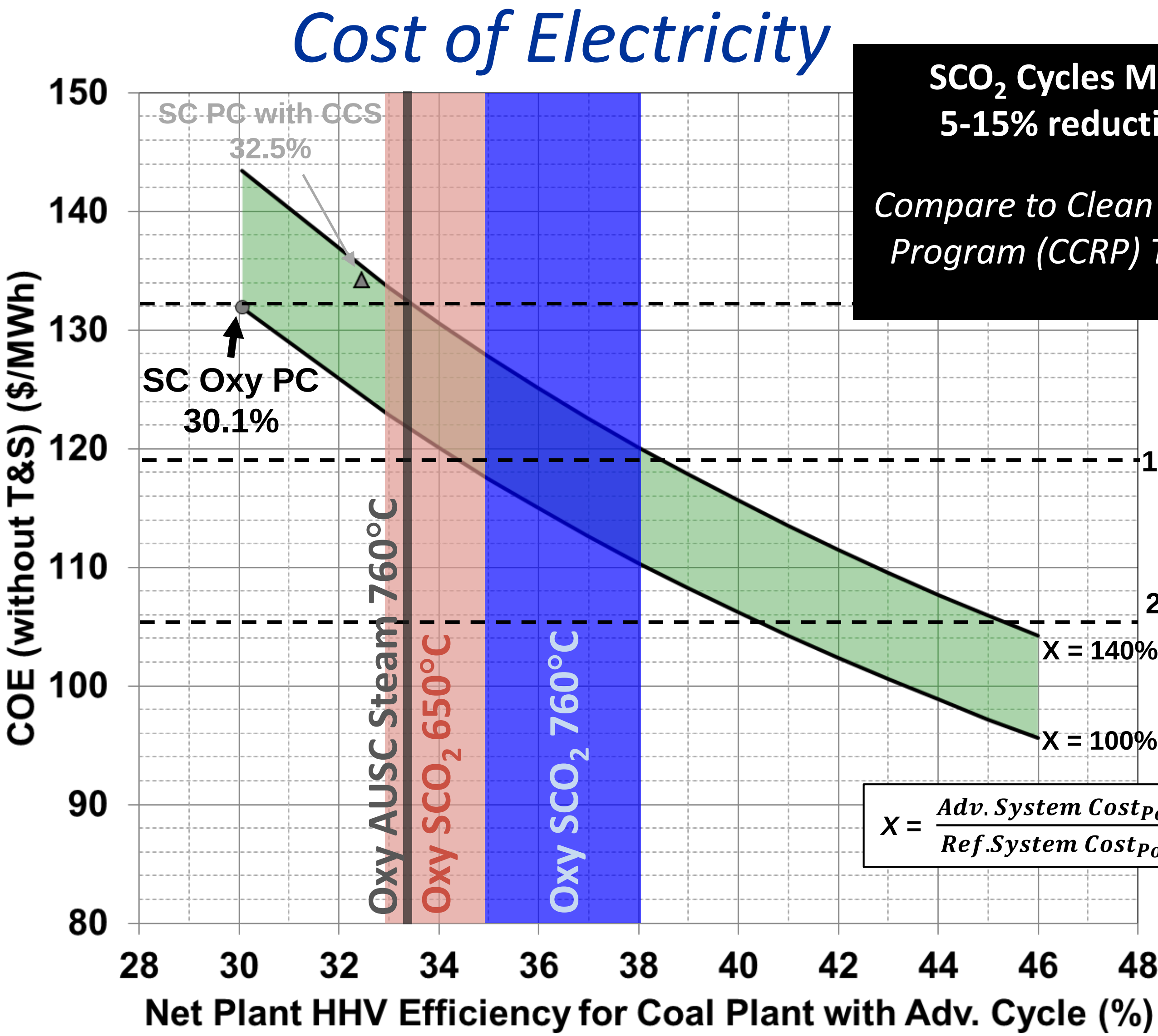
- **Minimal information available on SCO_2 power island costs**
  - Turbomachinery expected to have lower costs due to lower pressure ratios and greater power density of SCO_2 relative to steam cycles
  - Configurations achieving high efficiency requires use of recuperators with large heat transfer areas
  - In general, achieving higher efficiencies requires additional cost
- **Modifications to base coal plant anticipated for most configurations which will likely increase cost of the combustor and associated heat transfer piping**
- **Cost sensitivity approach for this analysis*:**

	Adv. System Cost (Power Island + Coal Combustor) / Ref. System Cost (Power Island + Coal Combustor)
Low	100%
High	140%



**Assumes all cost changes in total plant cost come from power island and coal combustor cost, which represent 32 % of the total plant cost of the reference SC oxycombustion system*

Cost-Efficiency Trade-off for Adv. Power Cycles



SCO_2 Cycles May Provide 5-15% reduction in COE

Compare to Clean Coal Research Program (CCRP) Target of 20%

Reference: SOA SC Oxy-combustion

550 MW

$$X = \frac{Adv.\,System\,Cost_{Power\,Island+Combustor}}{Ref.System\,Cost_{Power\,Island+Combustor}}$$

Source: NETL

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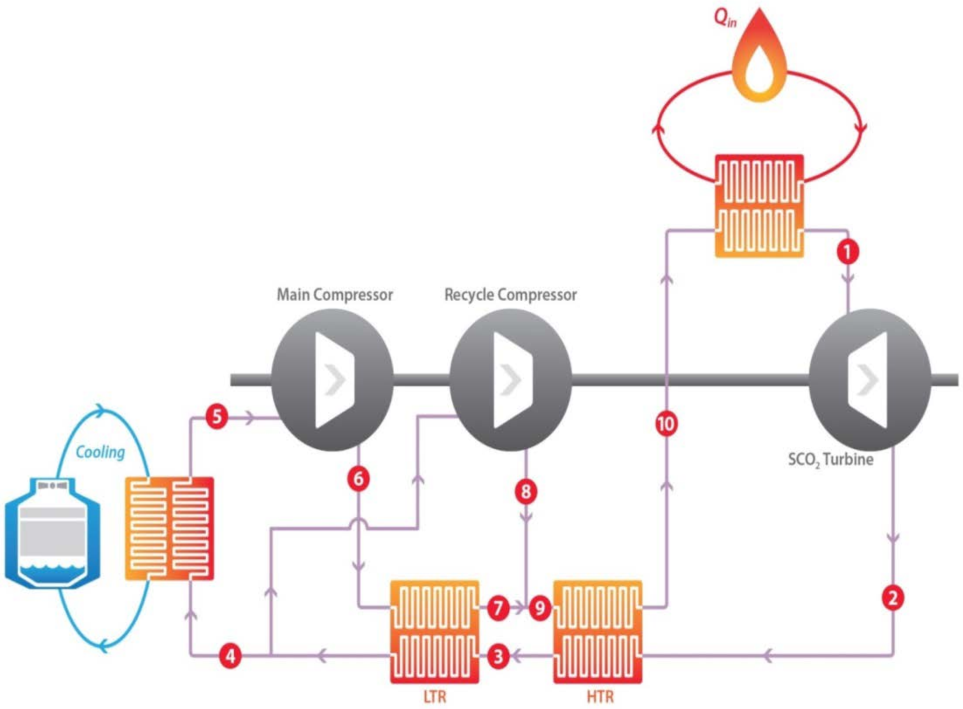
Potential Benefits for Coal-Based Indirect SCO_2 Cycles

- Applicable to multiple coal-based platforms (air and oxygen-fired, PC, CFB, PFBC)
- Substantial efficiency improvements anticipated as shown in table below
- Significant cost uncertainties associated with SCO_2 power island (eg. recuperators) and combustor modifications
- Result: SCO_2 cycles may provide 5-15% reduction in COE

Power Cycle	Net Plant HHV Efficiency Improvement • in coal plants with 90% capture • relative to SC steam cycle[1]	COE Change Attributable to Advanced Power Cycle	
		Low Cost[3]	High Cost[3]
AUSC Steam[2] 760°C (1400°F)	+3.5%pts	-7 to -8%	+1 to -0%
SCO_2 650°C (1200°F)	+3 to 5%pts	-6 to -11%	+2 to -3%
SCO_2 760°C (1400°F)	+5 to 8%pts	-10 to -16%	-2 to -9%

[1]SC = Supercritical 3500 psig/1100°F/1100°F
[2]AUSC = Advanced ultrasupercritical 5000 psig/1400°F/1400°F consistent with program targets
[3]"Low Cost" assumes combustor + power island costs same as SC steam case; "High Cost" assumes these sub-systems cost 40% more than for SC steam

No reduction
0 to 8%
> 8%



POTENTIAL POWER SECTOR BENEFITS FOR SCO_2 CYCLES

SCO_2 Power Cycle Preliminary Benefits Assessment: *Objective*

Identify potential national and international benefits associated with deployment of SCO_2 power cycle technology

- **Consider reductions in the cost of power generation, CO_2 emissions and water consumption**
- **Consider fossil, nuclear and concentrating solar power (CSP) applications**

SCO_2 Power Cycle Preliminary Benefits Assessment: *Approach*

- **Examine new capacity forecasts for each base plant technology using 2 bounding scenarios**
- **Simplified approach to estimating the cost and performance benefits of plants with SCO_2 power cycles focuses on thermodynamic benefits with limited information on cost of the SCO_2 power cycle**
  - Ranges used to represent significant uncertainty in both performance and cost creating an “optimistic” and a “pessimistic” case
- **Plants with SCO_2 power cycles assumed to displace notional percentages of new capacity additions of steam-turbine-based conventional technologies with the same fuel type (assumed values ranging from 25% - 75%)**
  - Coal displacement of NGCC is a lower notional percentage due to geographically-limited CO_2 sales (~$40/tonne) for use in EOR; coal based sCO_2 must compete with NGCC so deployment levels are also dependent on technology optimism and natural gas prices.

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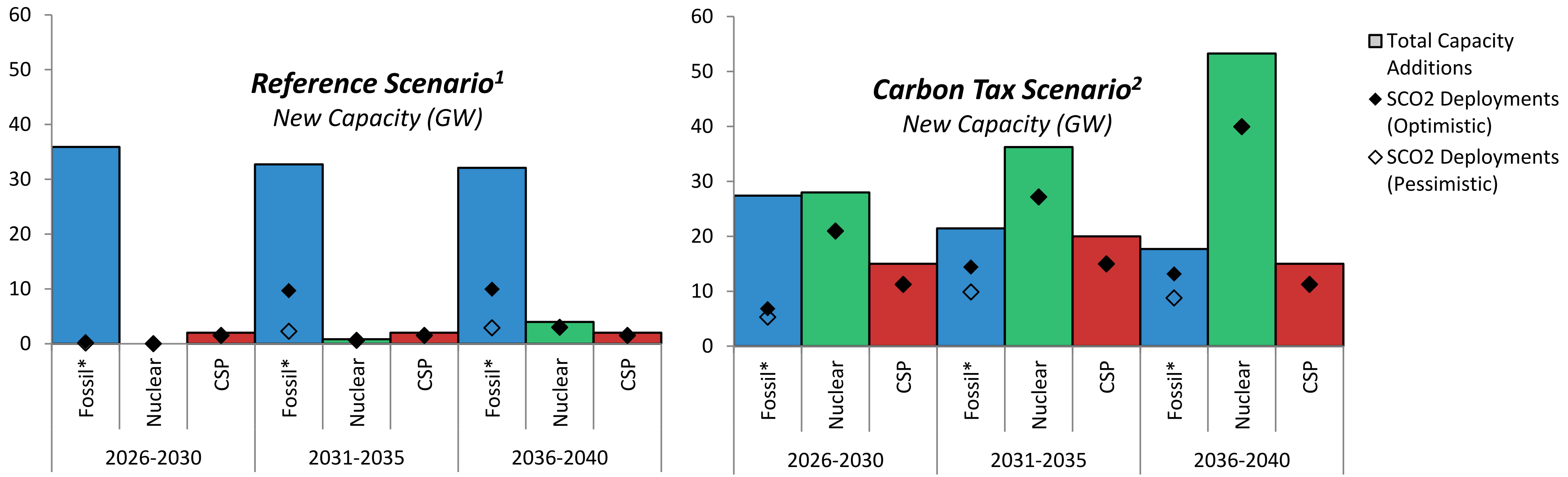
SCO_2 Power Cycle Preliminary Benefits Assessment: *Deployments*

Potential deployments heavily influenced by the price of natural gas and carbon incentives



*All baseline fossil deployments are NGCC and NGCC with CCS; SCO_2 technology allows for coal with CCS to displace some NGCC deployments

[1]AEO 2014 Reference Case except for CSP which is derived from IEA's ETF 2DS Scenario (CSP as depicted in AEO 2014 does not allow for CSP + storage requiring the use of alternate projections)

[2]AEO 2014 GHG25 Case ($25/tonne CO2 tax beginning in 2015, escalating by 5% per year, real) except for CSP which is derived from EERE's SunShot Vision Study

SCO_2 Power Cycle Preliminary Benefits Assessment: *Accrued Benefits Through 2040*

U.S. Benefits	**Reference Case**	**Carbon Tax Case**
Cost of Electricity Reduction for Fossil, Nuclear and CSP	~5-15%	
sCO_2 Capacity Deployed (GW)	13-28	150-160
Power Generation Cost Savings ($Billions)[1]	$0.6-$5	$8-$52
IRR Assuming $500M R&D Investment over 5 Years	10%-17%	29%-38%
Plant Level CO_2 Emissions Reduction (million tonnes)	0-172	80-89
International Benefits: Plant Level CO_2 Emissions Reduction (million tonnes)		14,700

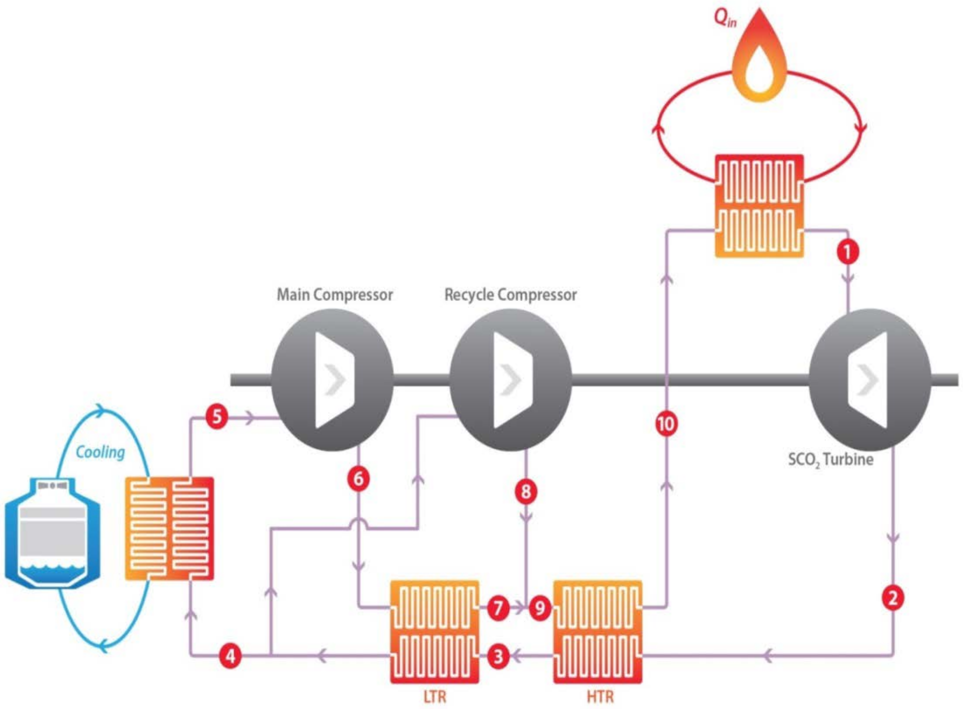
[1]2012 year dollars discounted at a 3 or 7% rate consistent with OMB A-94.

Results

- The ranges reflect uncertainties with technology performance, capital costs and natural gas price.
- U.S. GHG reductions are constrained by limited fossil displacement. Globally the CO_2 reduction is significant.
- Increased efficiency/reduced cost with sCO_2 enables coal with CCS (and EOR) to displace natural gas combined cycle w/o CCS.

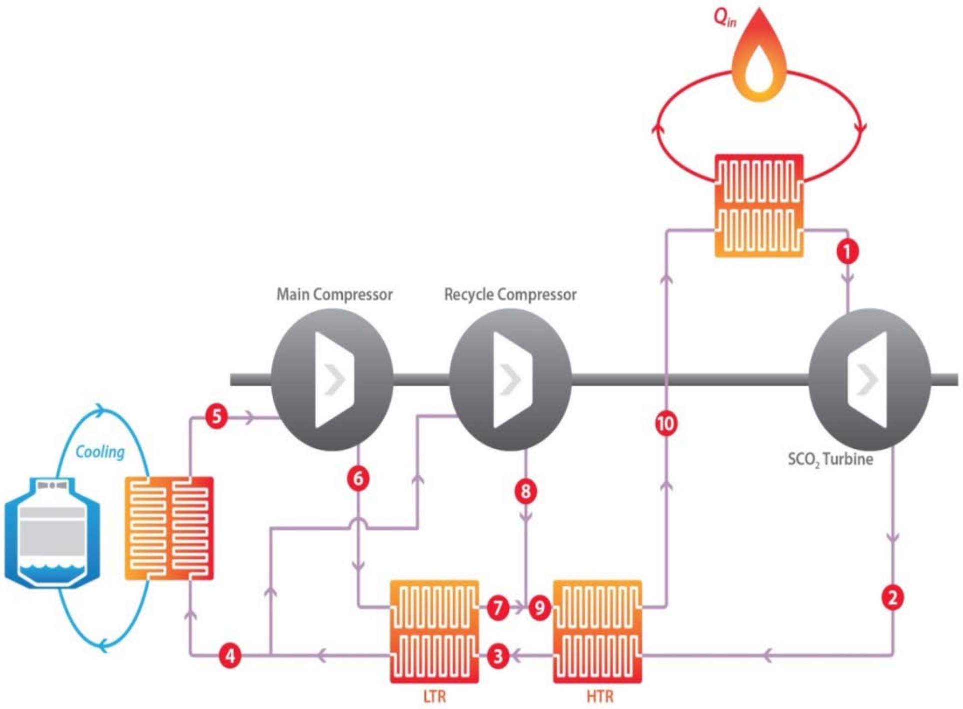
SCO2 power cycles are ideally suited for dry cooling:

- Each GW of coal with sCO_2 with dry cooling displacing NGCC with wet cooling saves ~2 billion gals/year of water.
- If 4 of the 17 GW projected coal systems shifted to dry cooling, water consumption would be reduced by ~75 billion gallons through 2040 (9 billion gals/year in 2040).



Q_in
Main Compressor
Recycle Compressor
SCO2 Turbine
Cooling
1
2
3
4
5
6
7
8
9
10
LTR
HTR

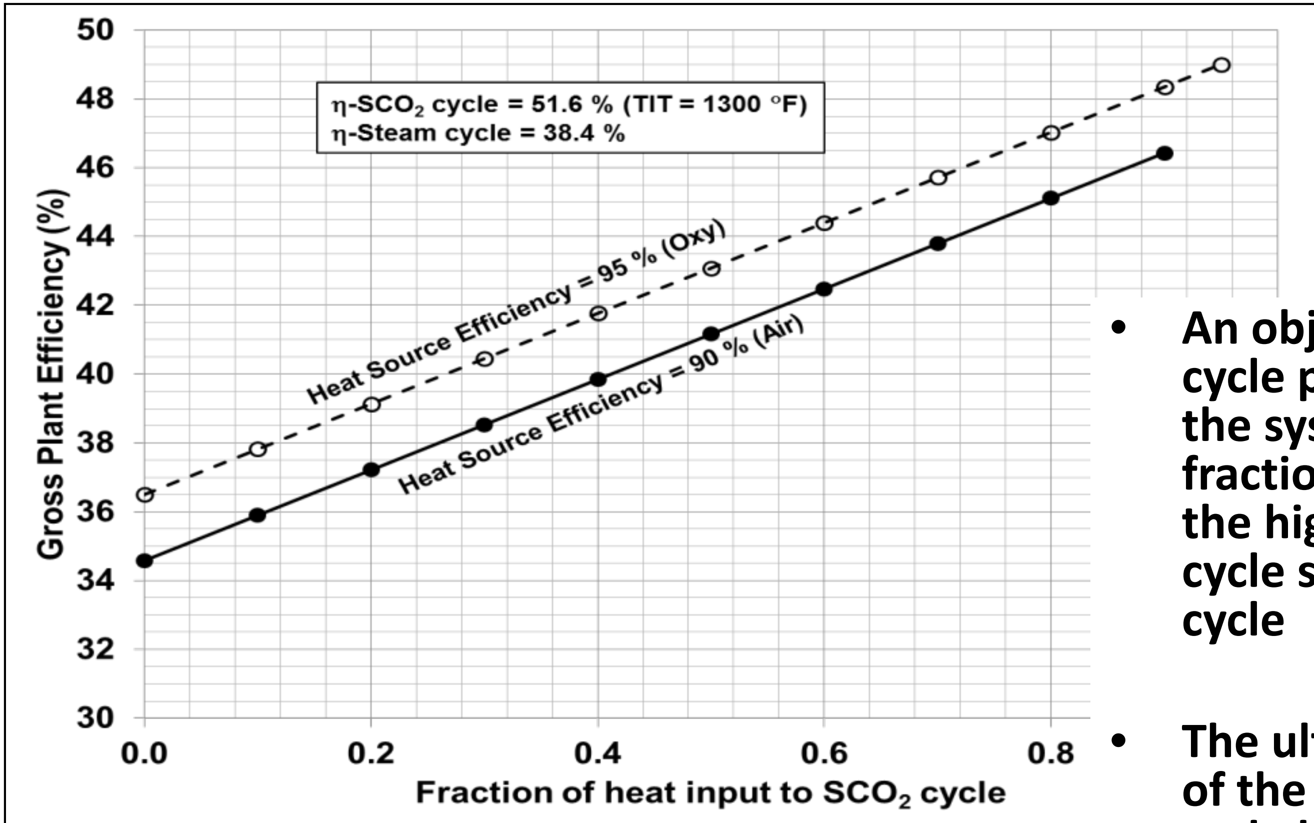
QUESTIONS?



BACK UP: SCREENING OF FOSSIL-BASED HEAT SOURCES FOR INDIRECT SCO_2 CYCLES

Matching Heat Sources to Power Cycles

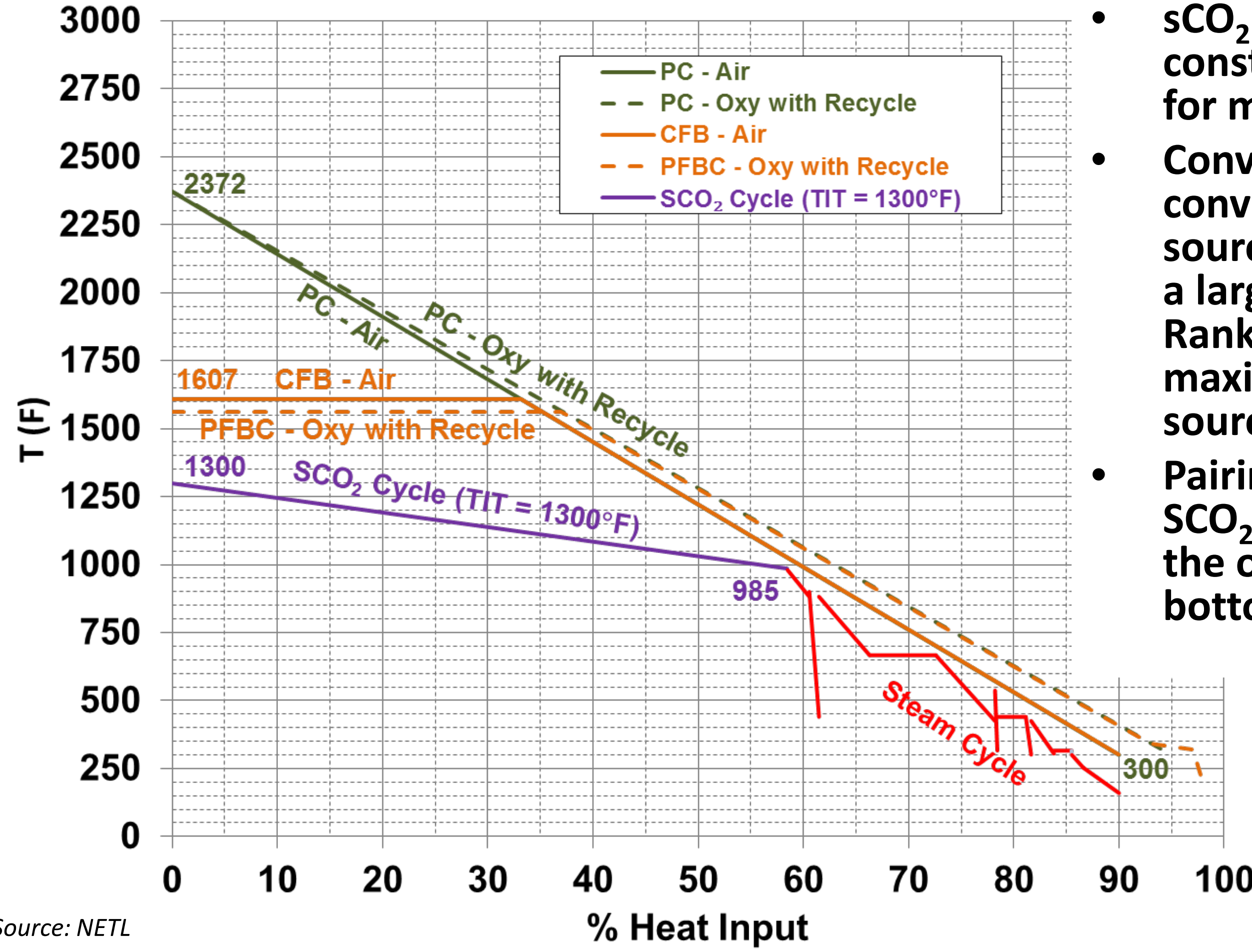
Minimizing Bottoming Cycles



- An objective with combined cycle power plants is to design the system to maximize the fraction of input heat going to the higher efficiency topping cycle such as a sCO_2 Brayton cycle
- The ultimate goal is to use all of the input heat in the topping cycle but this is often difficult without wasting lower level heat

Matching Heat Sources to Power Cycles

T-Q Diagram for Conventional Coal-Based Systems and example indirect SCO_2 cycle

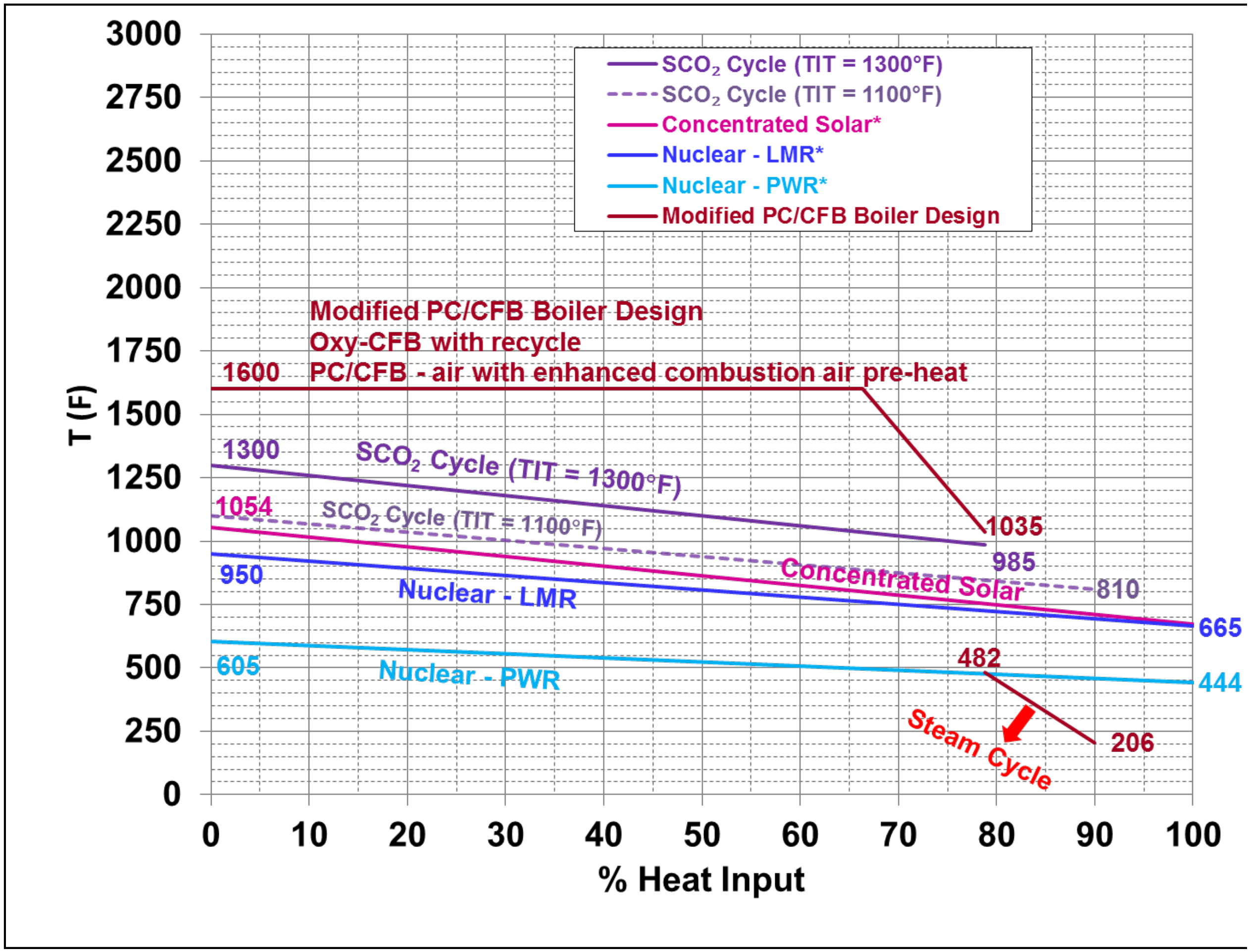


Source: NETL

- sCO_2 cycle requires a relatively constant temperature heat source for maximum plant efficiency.
- Conventional PC, CFB, and conventional oxy-combustion heat sources provide a heat source with a large slope of T versus Q. Steam Rankine cycles have been tuned to maximize the use of this heat source temperature profile.
- Pairing theses heat sources and SCO_2 power cycle does not meet the objective of minimizing the bottoming cycle.

Matching Heat Sources and Power Cycles

T-Q Profiles of Modified Coal-Based Systems



- **Adding enhanced preheat for combustion air or CO_2 recycle enables conventional PC, CFB, and PFBC air and oxy heat sources to be tailored to match the T versus Q profile required for a sCO_2 cycle.**

- **Modifications allow multiple coal-based systems (air, oxy, CFB, etc) to serve as a heat source for indirect SCO_2 power cycles while meeting the objective of minimizing the bottoming cycle.**