Coal Fired Heater for 1400F (760C) Supercritical Carbon Dioxide

increase temperature to improve efficiency

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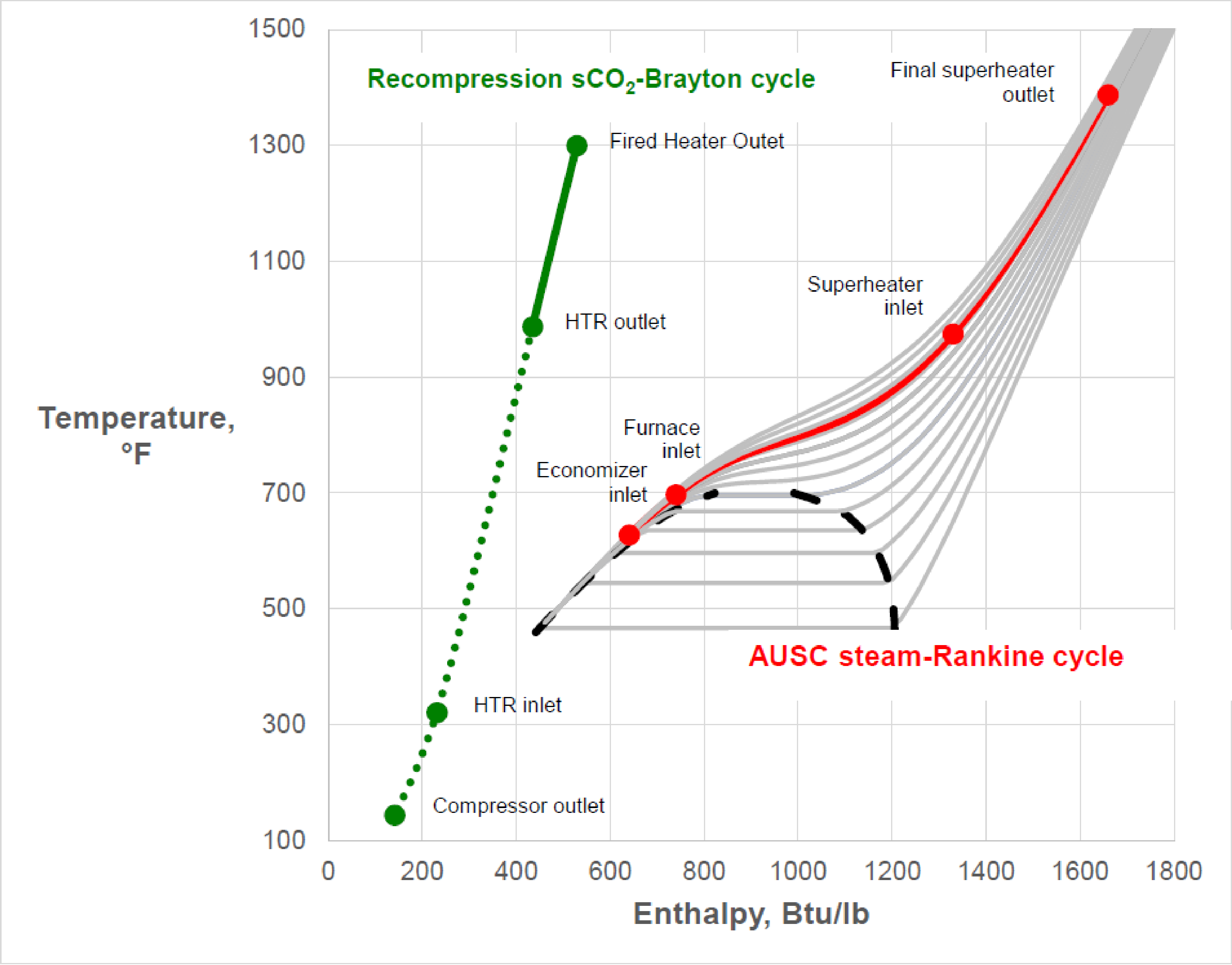
Tempereature - Enthalpy

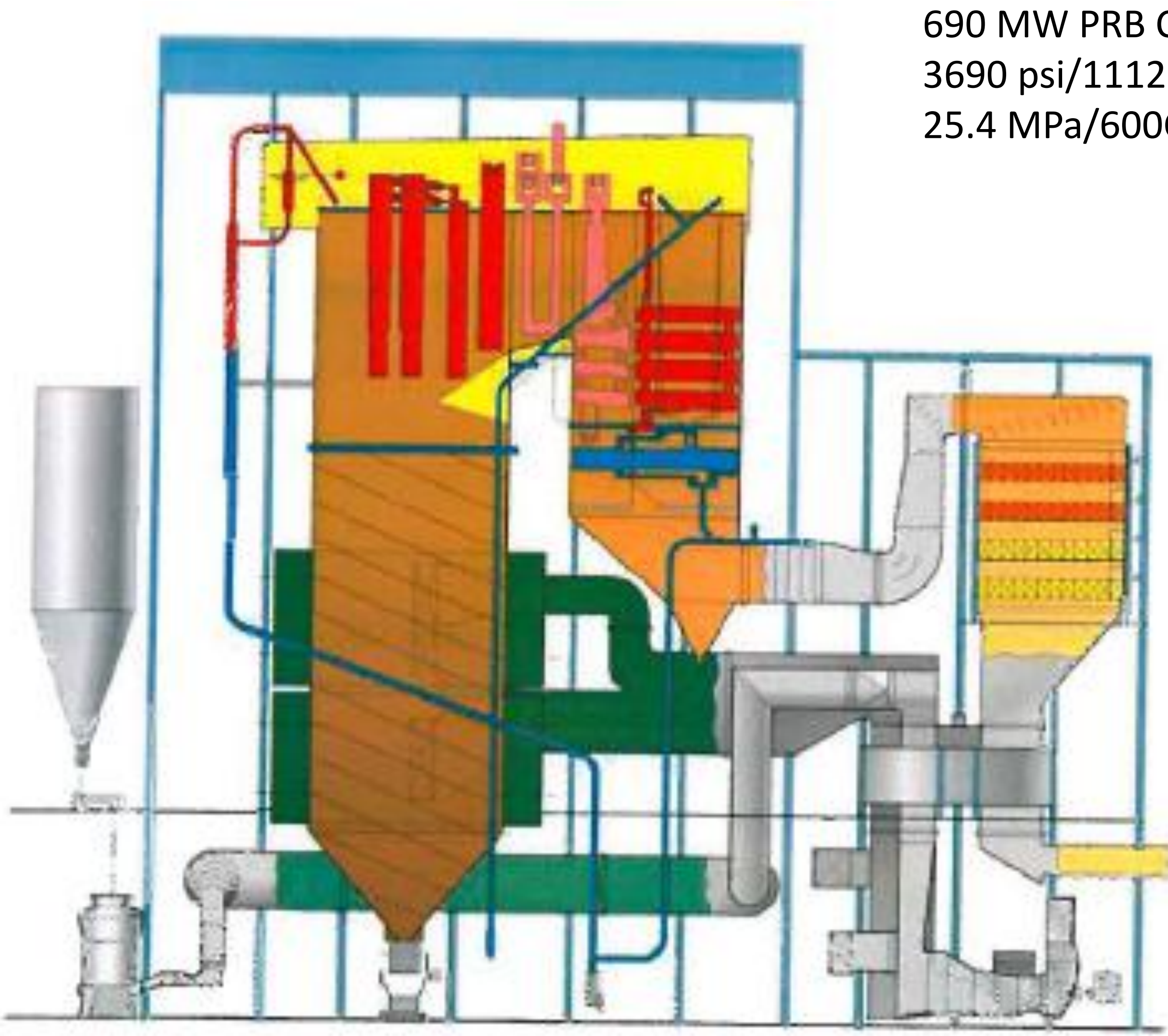


Comparison of Power Cycle Parameters

Parameter	Baseline AUSC Rankine Cycle	Recompression	Cascaded
Net Output (MW_e)	750	750	73
Working Fluid Mass Flow Rate (klb/hr)	4,620	52,320	6,144
Throttle Pressure (psi)	5085	3000	3000
Throttle Temp (°F)	1256	1300	986
Working Fluid Specific Volume (ft^3/lb)	0.1782	0.1497	0.1214
Working Fluid Volume Flow Rate (ft^3/min)	13,720	130,540	12,430
Reheat Temp (°F)	1292	n/a	n/a
Feed Temp (°F)	649	987	147
Inlet Pressure (psia)	5670	3020	3020
Specified Heater Pressure Drop (psid)	585	20 (not achieved)	
Heat Input (million Btu/hr)	5,930	6,759	
Fired Heater Efficiency (HHV)	87.1%	87.3%	

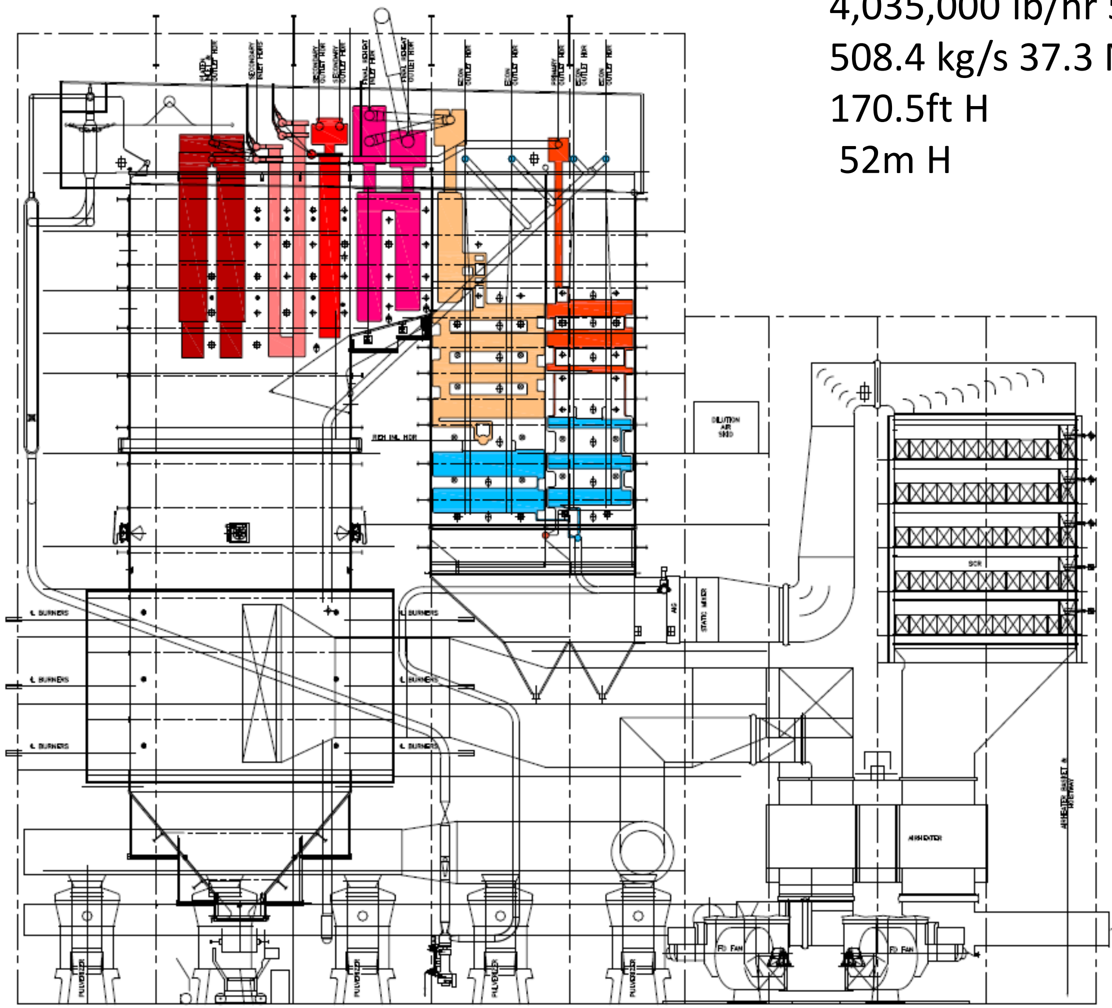
USC 600C/610/C AEP JW Turk

690 MW PRB Coal
3690 psi/1112F/1129F
25.4 MPa/600C/610C

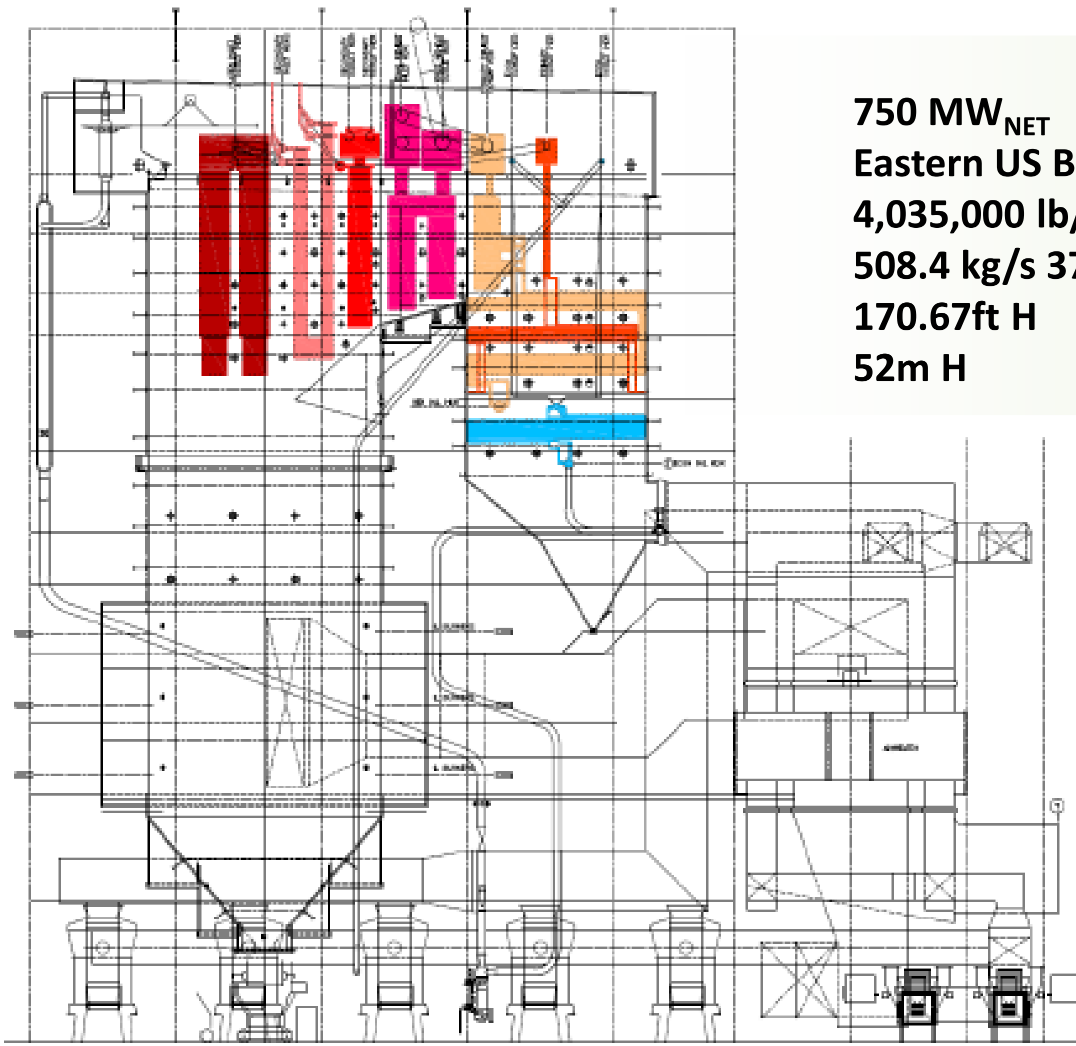


2014 A-USC Air Fired

Eastern US Bituminous Coal
4,035,000 lb/hr 5250 psi 1356F/1401F
508.4 kg/s 37.3 MPa 735C/760C
170.5ft H
52m H



2014 A-USC Oxy-Combustion



750 MW_{NET}
Eastern US Bituminous Coal
4,035,000 lb/hr 5250 psi 1356F/1401F
508.4 kg/s 37.3 MPa 735C/760C
170.67ft H
52m H

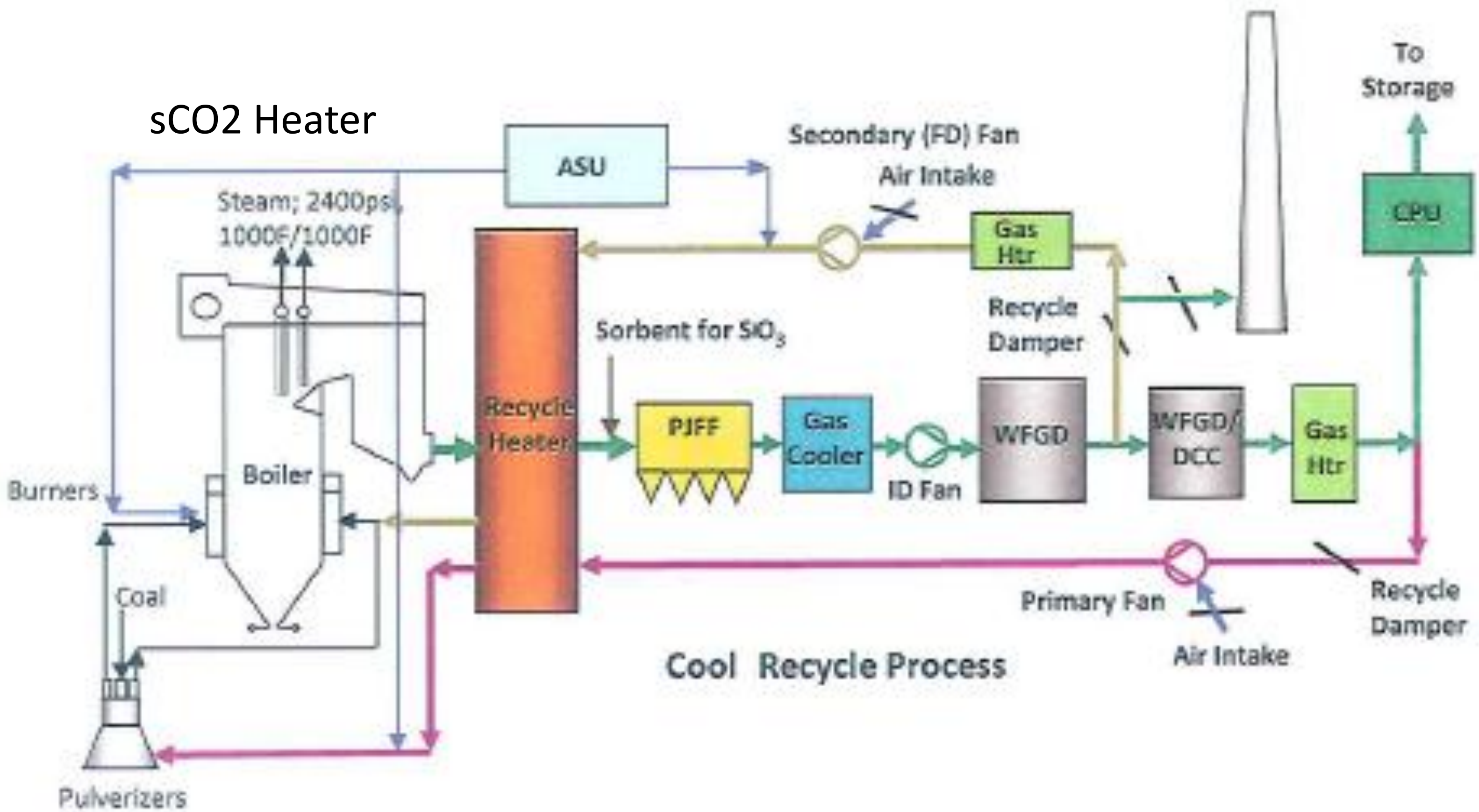
Oxy-Combustion

↓

lower cost A-USC boiler

A-USC + CCS lowers costs of carbon capture

Oxy Combustion – Cool Recycle



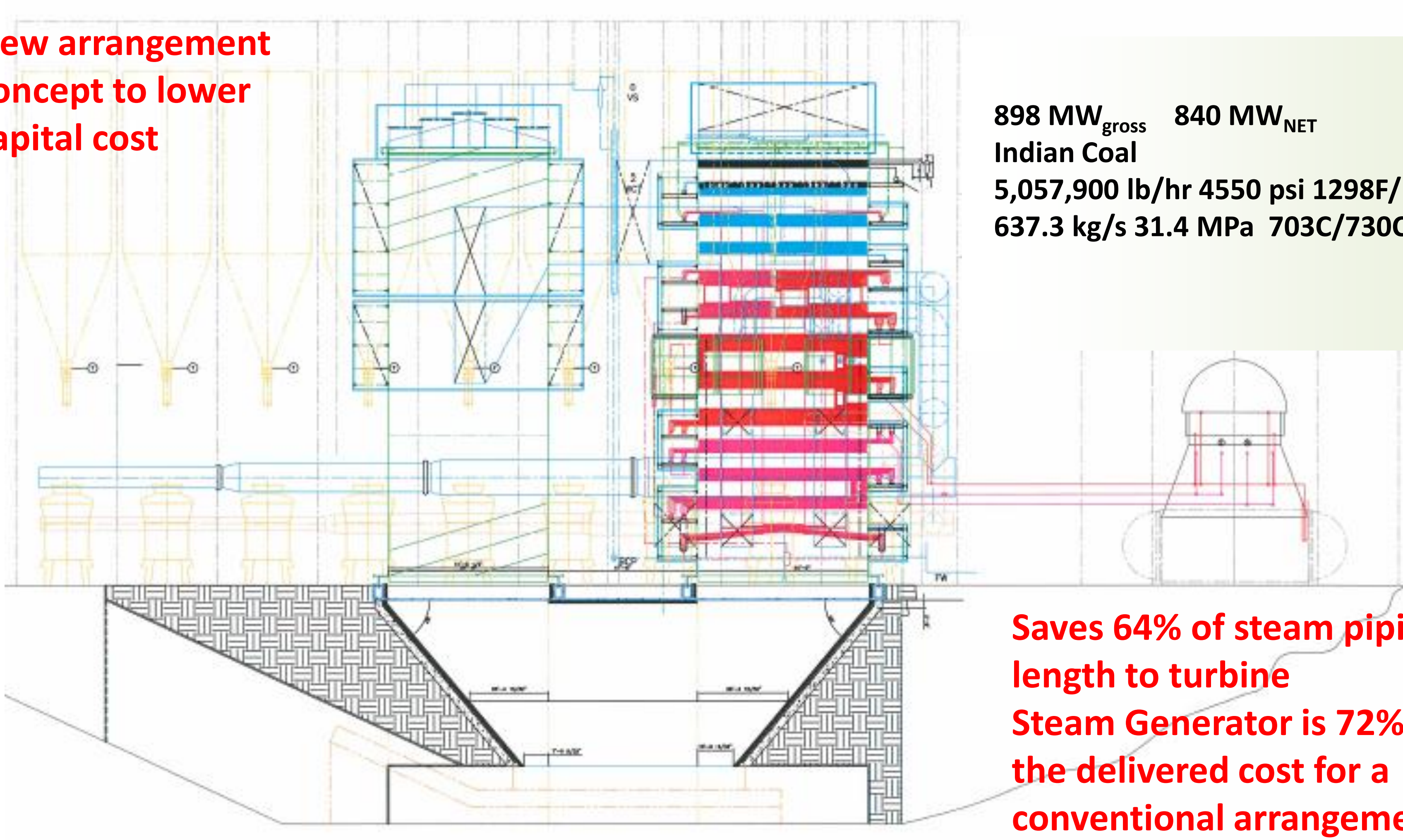
Use less water - sCO2 cooled heat exchangers needed @ ASU, CPU, DCC, gas cooler/heater systems?

Dry cooling - No wet cooling tower?

Downdraft Inverted Tower

Patent EU 14187421.4-1610

New arrangement concept to lower capital cost

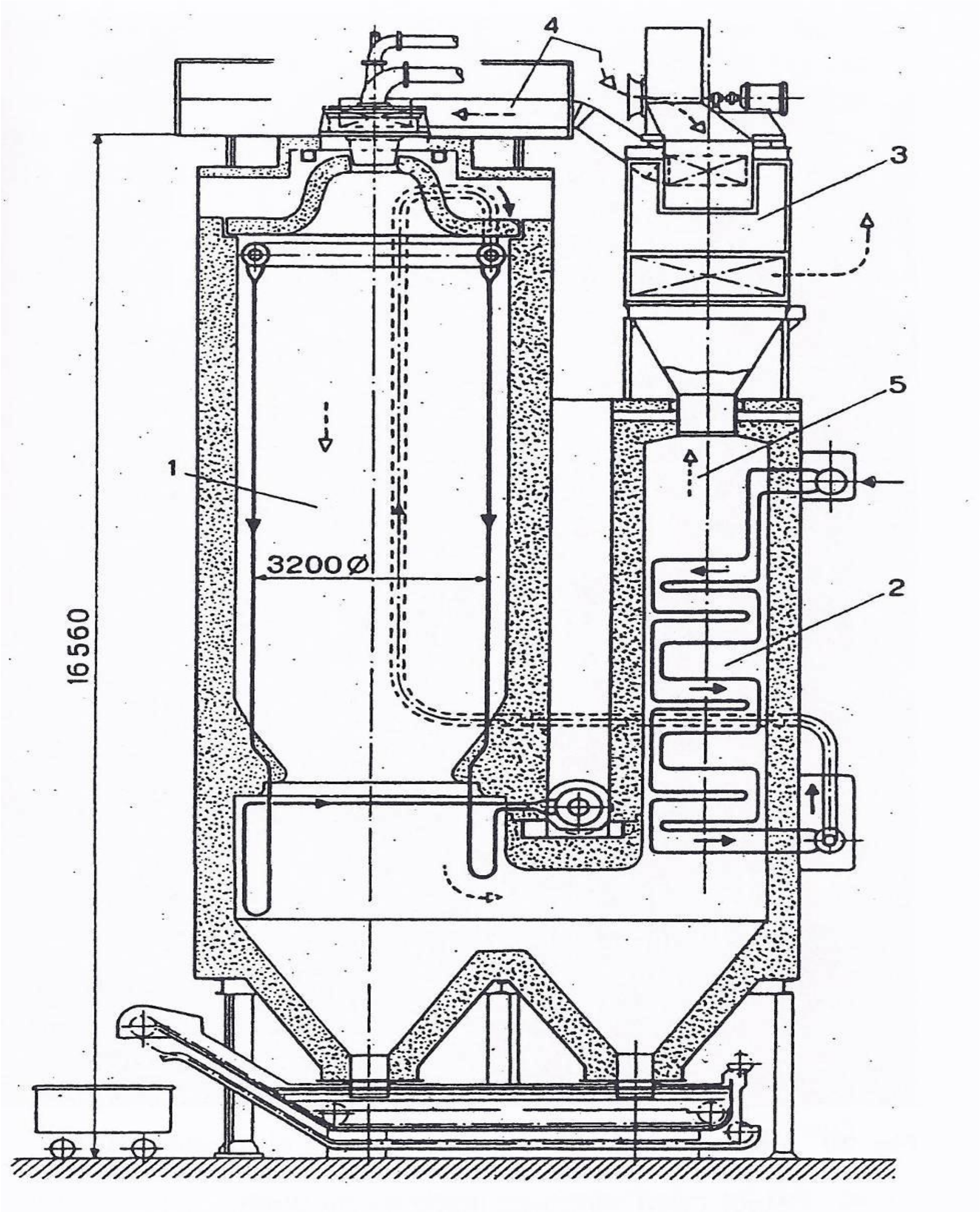


898 MW_{gross} 840 MW_{NET}
Indian Coal
5,057,900 lb/hr 4550 psi 1298F/1347F
637.3 kg/s 31.4 MPa 703C/730C

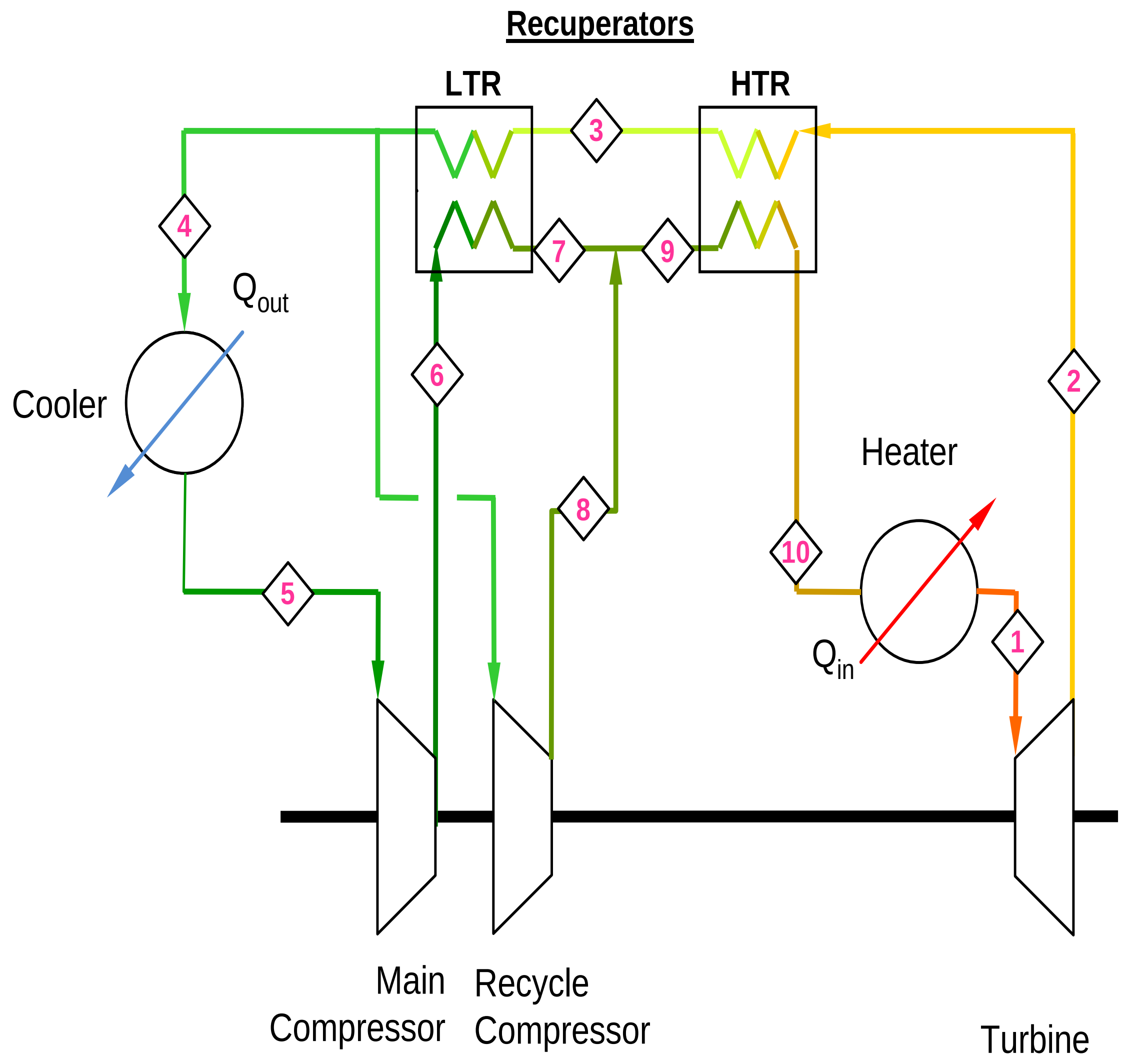
Saves 64% of steam piping length to turbine
Steam Generator is 72% of the delivered cost for a conventional arrangement

Not developed on DOE/OCDO project

Escher Wyss Ravensburg Germany 1950's Brayton Cycle Coal Fired Air Heater



Recompression sCO2 Brayton Cycle



Main power cycle cools combustion products to ~1200F

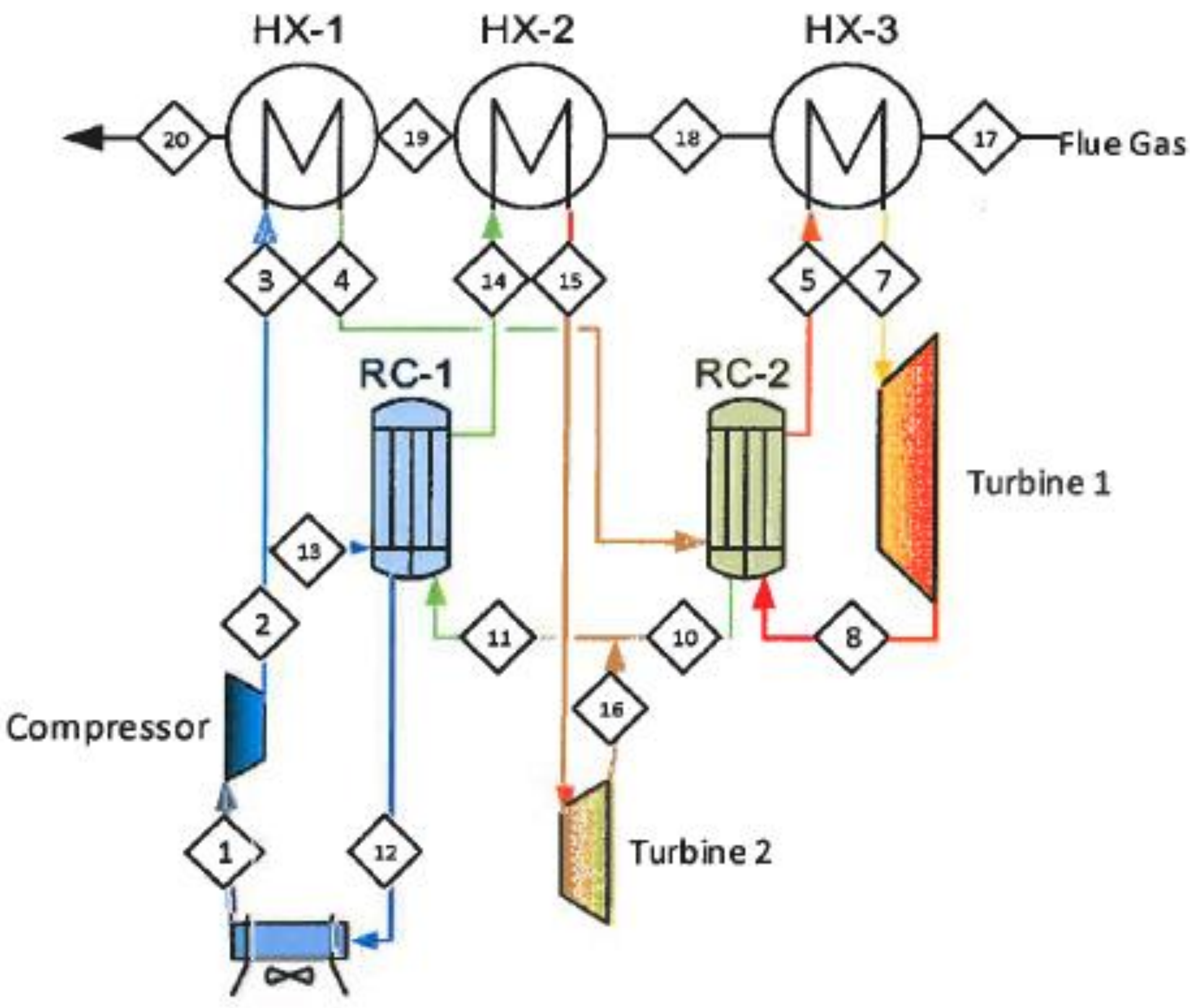
Recompression sCO2 Brayton Cycle

Tag	Stream	Flow klb/hr	T °F	P psia	Enthalpy Btu/lbm	Entropy Btu/lbm-R	Efficiency %	Power MW
1	Heater 1 Out	52,320	1300	3000	528.59	0.70503		
2	Turbine Out	52,320	1070	1143	463.21	0.70982	90%	1002.5
3	HTR Hot Out	52,320	332	1134	259.07	0.52876		
4	LTR Hot Out	31,915	154	1122	204.34	0.45028		
5	Cooler Out	31,915	89	1110	130.74	0.32000		
6	Main Compressor Out	31,915	144	3050	140.62	0.32246	85%	-92.5
7	LTR Cold Out	31,915	320	3035	230.34	0.45449		
8	Recycle Compressor Out	20,405	322	3035	231.09	0.45545	85%	-160.0
9	HTR Cold In	52,320	321	3035	230.63	0.45486		
10	HTR Cold Out	52,320	987	3020	434.77	0.64604		

Gross Power	**1002 MW**
Net Power	**750 MW**
Heat Added	**1438 MWth**
Cycle Efficiency	**52.1%**

Figure 1
Recompression sCO_2 Brayton Power Cycle Configuration and State Points
(HTR = high-temperature recuperator, LTR = low-temperature recuperator)

Cascade sCO2 Brayton Cycle



Bottoming power cycle cools combustion products from ~1200F to 700F

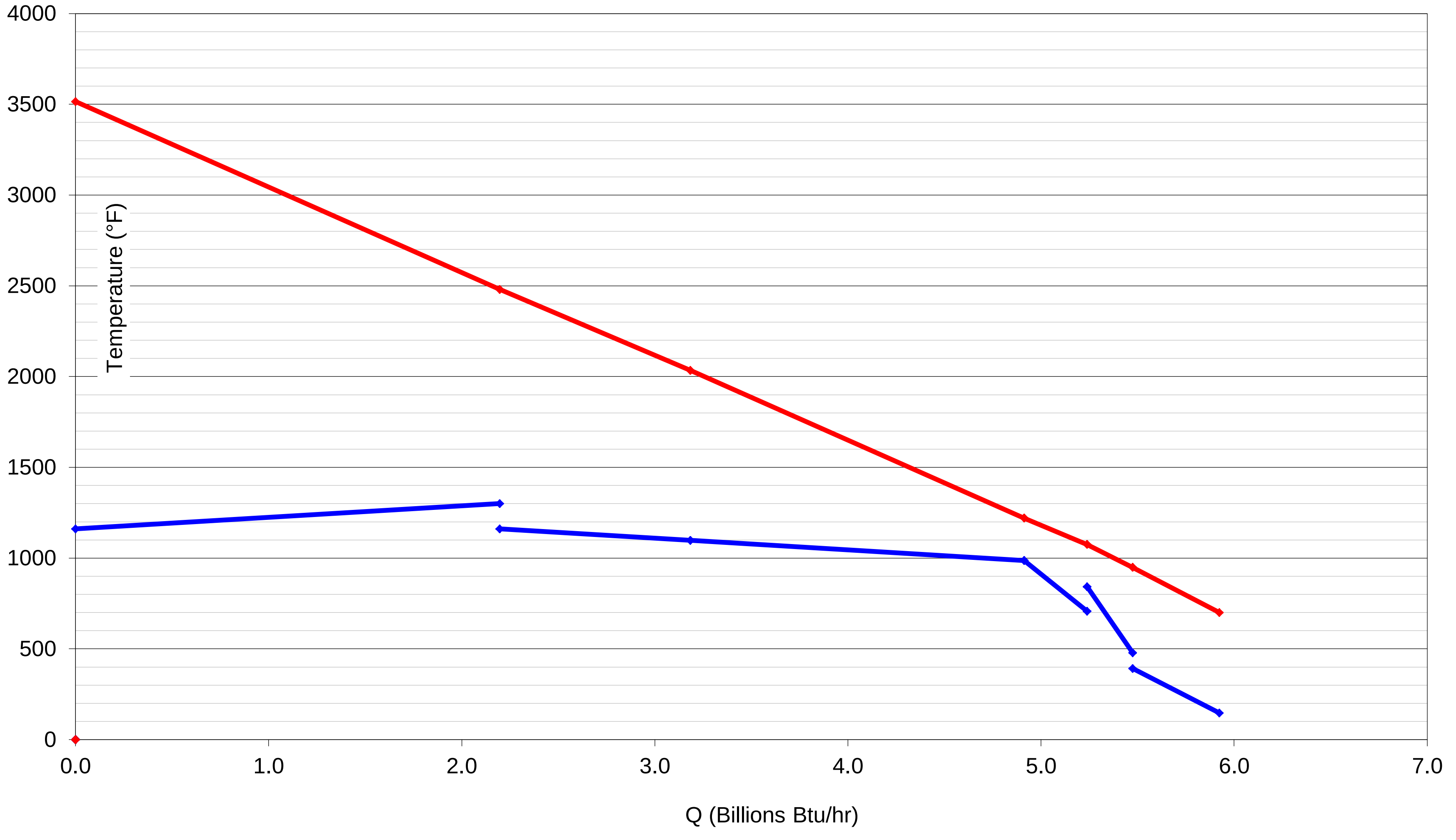
Cascade sCO2 Brayton Cycle

Tag	Stream	Flow klb/hr	T °F	P psia	Enthalpy Btu/lbm	Entropy Btu/lbm-R	Efficiency %	Power MW
1	Compressor In	6144	90	1117	131.7	0.3216		
2	Compressor Discharge	6144	146	3092	141.8	0.3241	85%	-18
3	HX-1 CO_2 In	3963	146	3092	141.8	0.3241		
4	HX-1 CO_2 Out	3963	392	3062	255.5	0.4849		
5	HX-3 CO_2 In	3963	707	3032	325.1	0.5822		
7	Turbine 1 In	3963	986	3002	434.2	0.6457		
8	Turbine 1 Out	3963	783	1150	381.7	0.6504	90%	61
10	RC-2 Low-Pressure Out	3963	428	1139	285.0	0.5593		
11	RC-2 Low-Pressure In	6144	506	1139	306.0	0.5821		
12	Compressor Inlet Cooler In	6144	320	1128	255.7	0.5246		
13	RC-2 High-Pressure In	2181	146	3092	141.8	0.3241		
14	HX-2 CO_2 In	2181	479	3062	283.5	0.5162		
15	Turbine 2 In	2181	842	3031	391.6	0.6142		
16	Turbine 2 Out	2181	648	1139	344.3	0.6190	90%	30

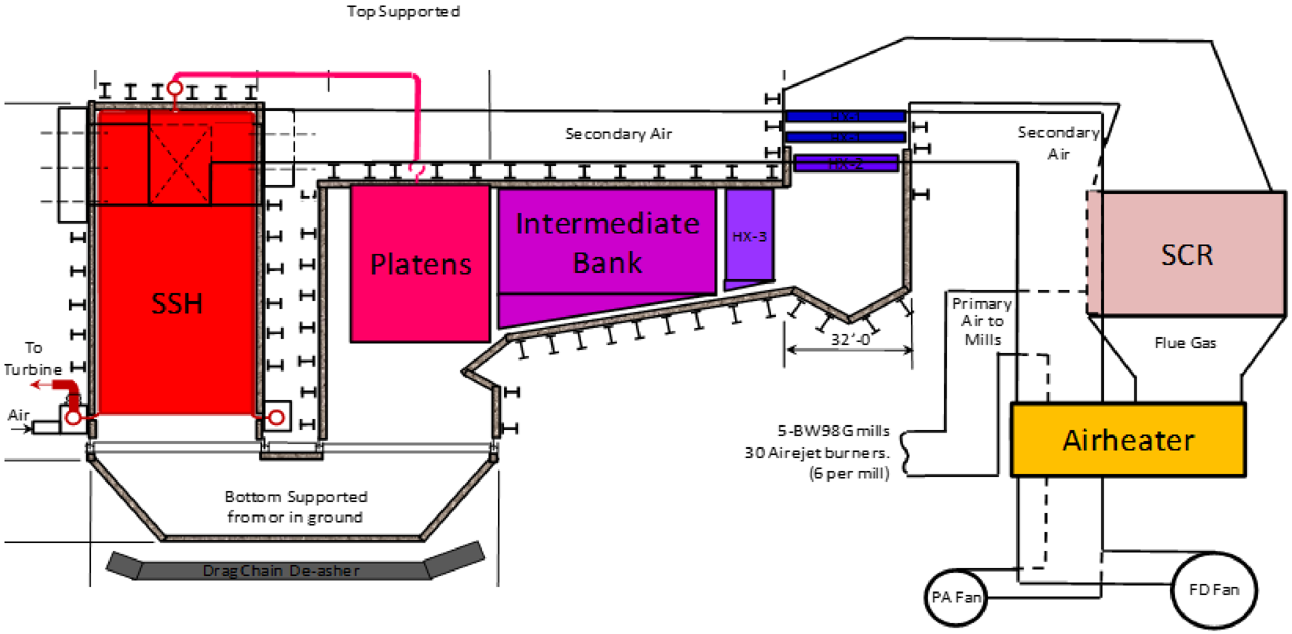
Gross Power	**91 MW**
Net Power	**73 MW**
Heat Added	**293 MWth**
Cycle Efficiency	**25 %**

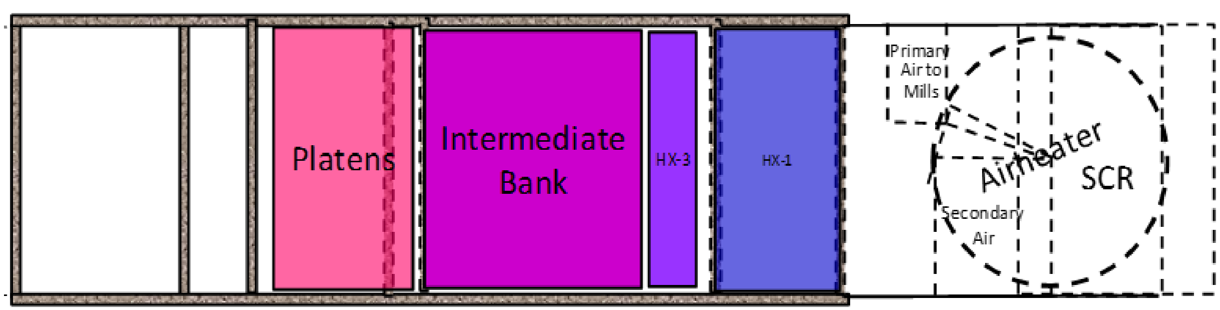
Figure 2
Cascaded sCO_2 Brayton Power Cycle Configuration and State Points
(HX = heat exchanger, RC = recuperator)

Temperature - Absorption



Coal Fired Heater Arrangement





Working Fluid Flow Path

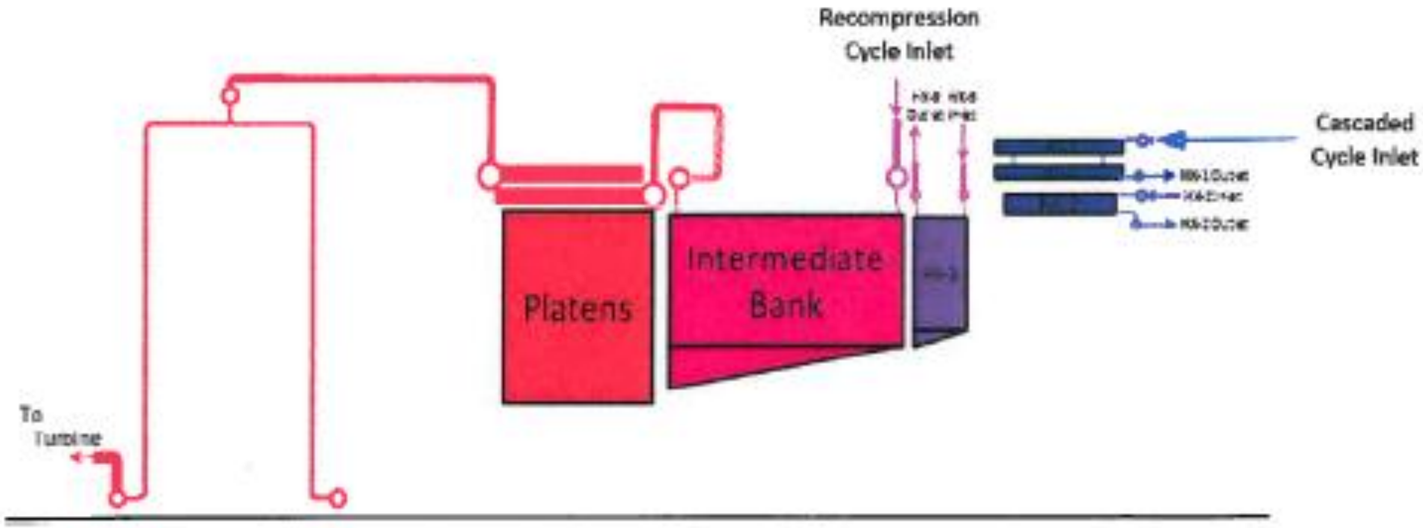
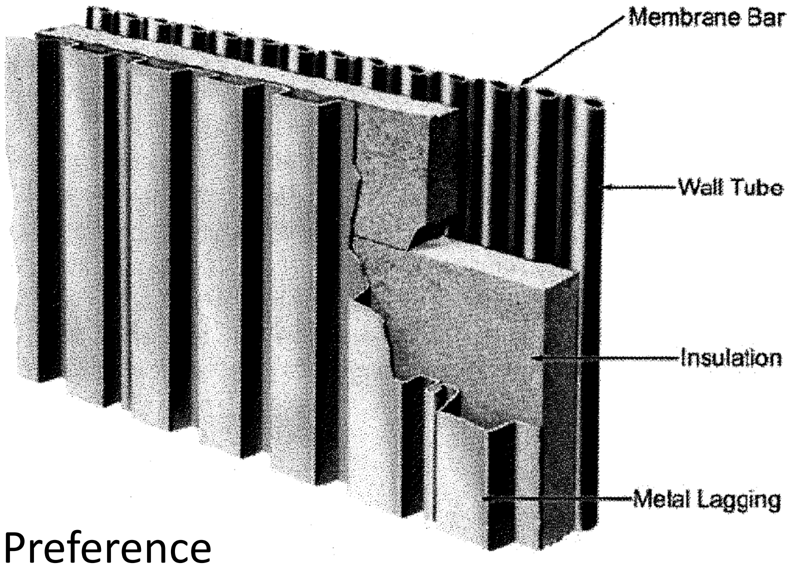
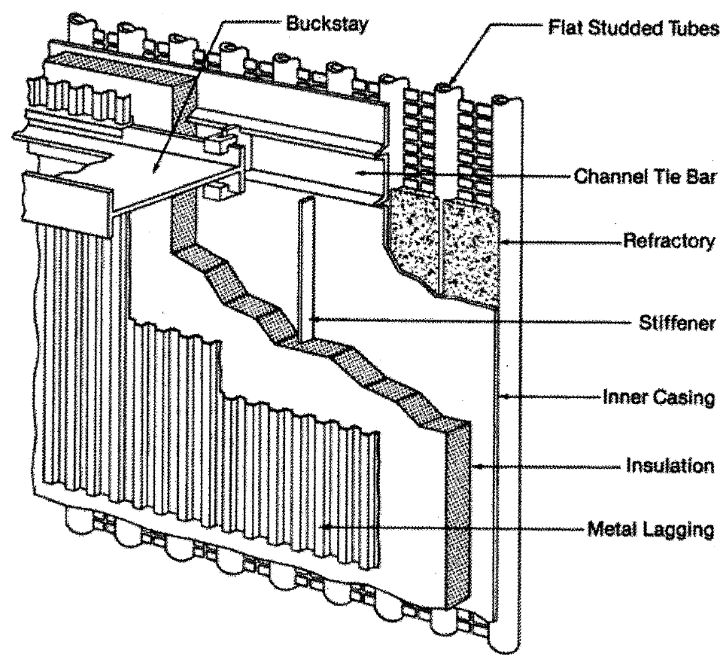


Figure 4
Coal-Fired sCO_2 Heater Working Fluid Flow Schematic

Gas Tight Welded Membrane Enclosure and Flat Stud Tube & Pressure Casing Enclosure

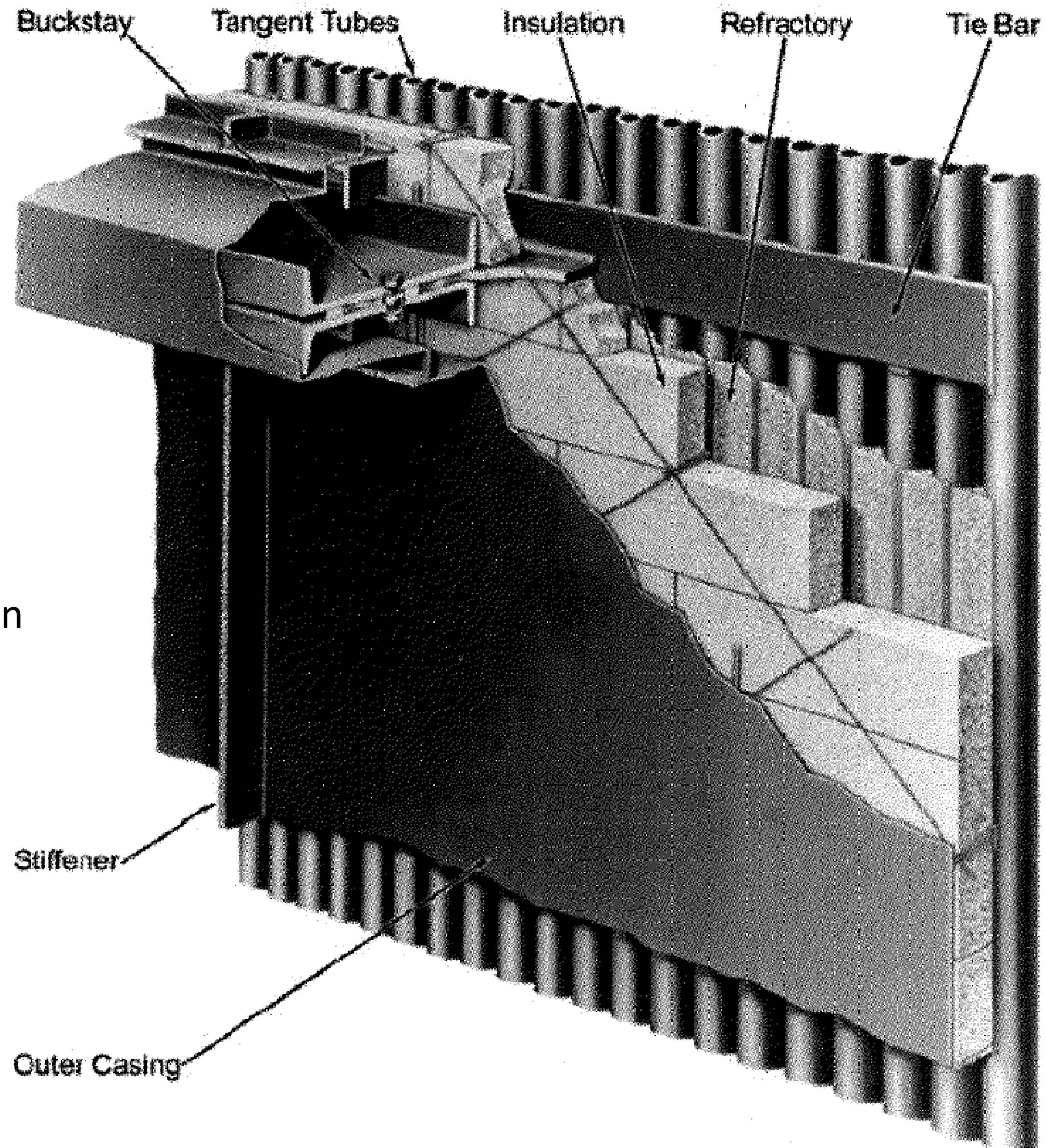


First Preference



Second Preference

Tangent Tube & Pressure Casing Enclosure



Obsolete Design

The Major Issues

Higher working fluid flow per gross kW for heat engines:

A-USC Steam	5.62 lb_{steam} / kWhr
7F GT	15 lb_{air} / kWhr
7E GT	20 lb_{air} / kWhr
sCO2 recompression	52.2 lb_{sCO2} / kWhr
sCO2 cascade	25 lb_{sCO2} / kWhr

More fluid transport pipe flow area needed to expander

Pressure drop desired is on the level of a reheater, not a steam generator superheater & furnace enclosure

Recompression cycle – needs very high temperature air heater, air ducts/gas flues, windbox, burners

Welded enclosure wall cooling fluid @ temperature beyond state-of-the-art practice

Δp ratio sCO2 to steam

$\Delta p_{sCO2} / \Delta p_{AUSCsteam} = (fL\,\dot{m}^2 / \rho\, D^5)_{sCO2} / (fL\,\dot{m}^2 / \rho\, D^5)_{AUSCstm}$
@ 1400F 3300 psia

Therefore- with the same geometry L, D & same output power capacity:

$\Delta p_{sCO2} / \Delta p_{AUSCstm} = (0.00655 * 52.2^2 / 6.908)_{sCO2} / (0.00761 * 5.62^2 / 3.154)_{AUSCstm}$

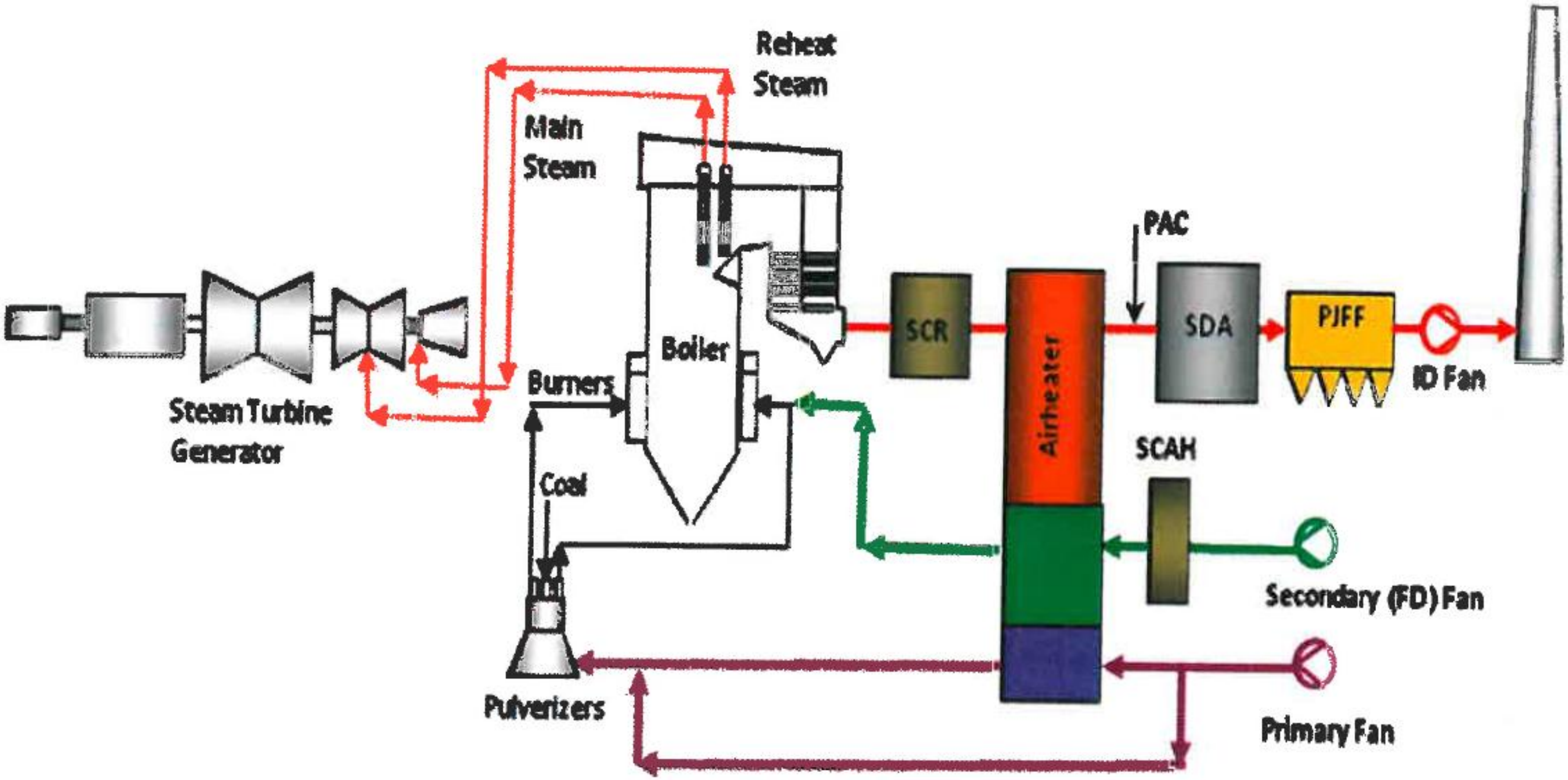
$\Delta p_{sCO2} / \Delta p_{AUSCsteam} = 33.9$

More cost for the heater flow path & two turbo-expanders to pipe up (1400F & 1000F) - so if turbine is smaller and saves $-

the other heat exchangers and fired heater are larger

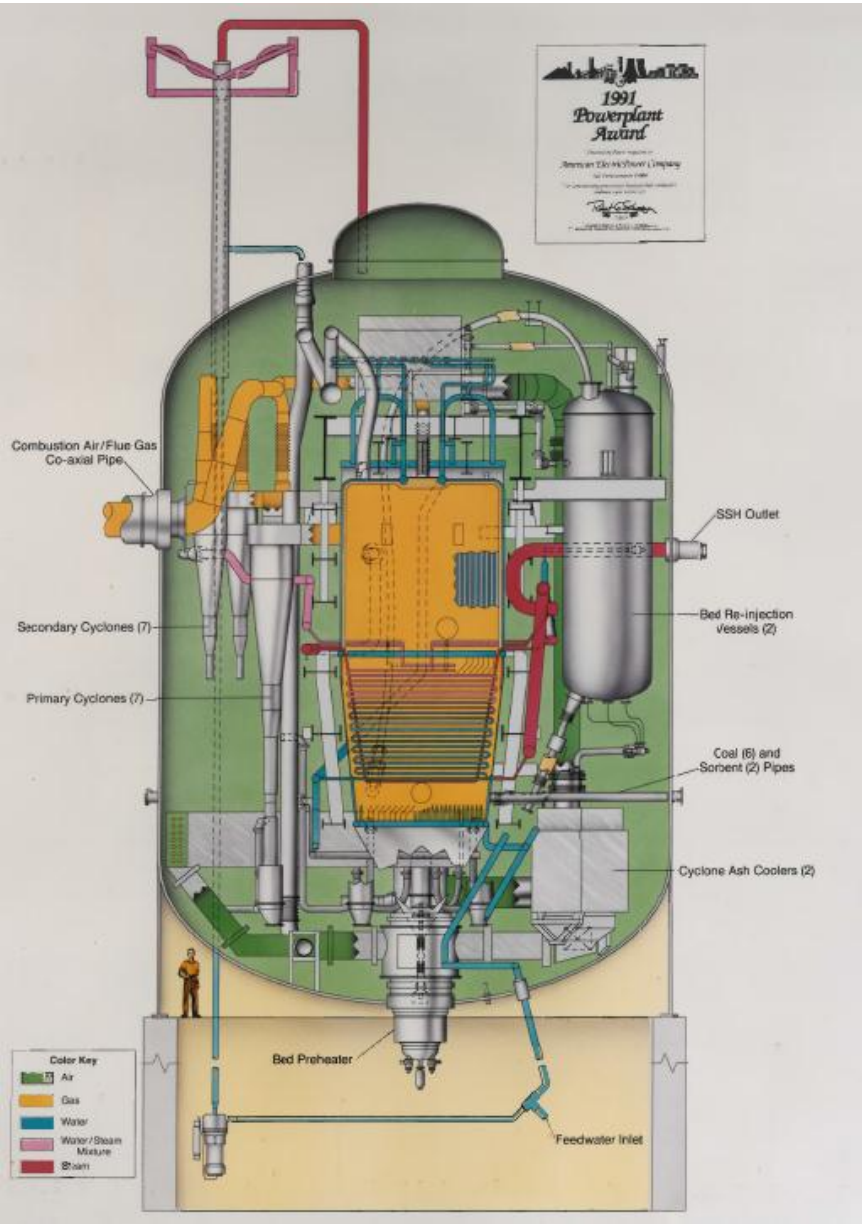
Will total $ be lower & does high efficiency really meet ROI?

Coal Fired Steam Plant



Once Through Supercritical Steam Generator has Filter / Demineralizer Pre-feedwater system
Natural circulation drum plant has provision for solids blowdown
Gas Turbine plant has an inlet air filtration system
Is there a need for a sCO2 working fluid clean up system?

AEP Tidd PFBC



Thank You!

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