CO2 Summit: Technology and Opportunity
Vail, Colorado, June 6-10, 2010

Thermodynamic Analysis of an Oxy-Combustion Process for Coal-Fired Power Plants with CO2 Capture

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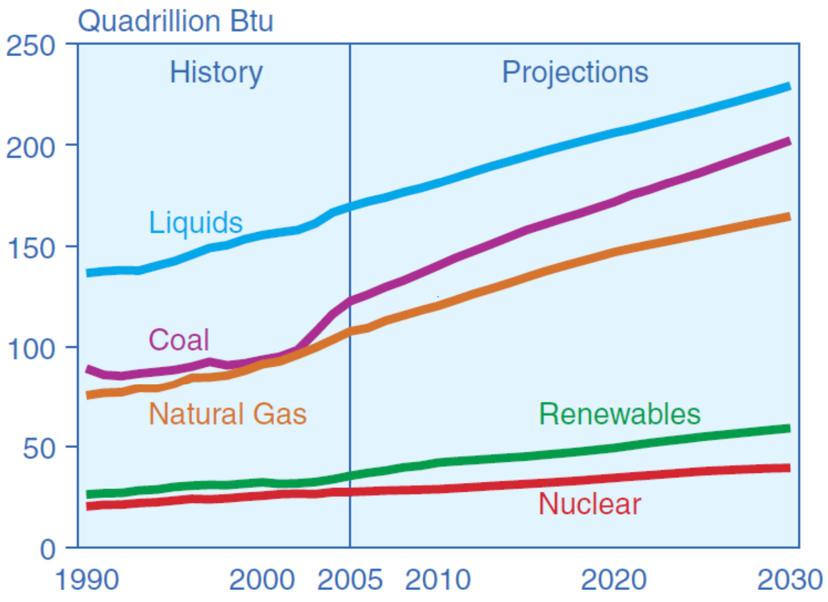
Outline of the Presentation

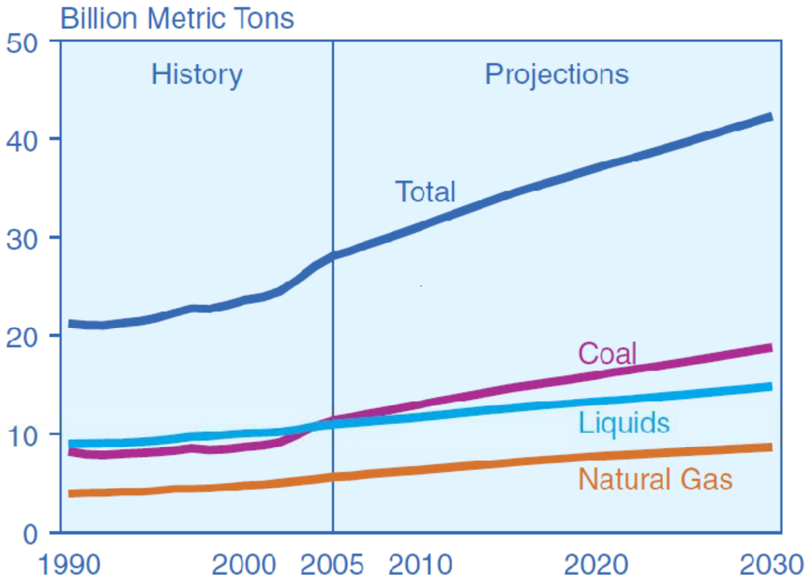
- Motivation
- Power Plant
- Exergy Analysis
- Efficiency Improvements
- Conclusions

Motivation

Energy Related CO2 Emissions



World marketed energy use*



World energy related CO2 emissions*

- **Coal becomes a more important energy source in the future**
- **Coal related CO2 emission represents an increasingly larger part**
- **Carbon Capture & Storage (CCS) :**

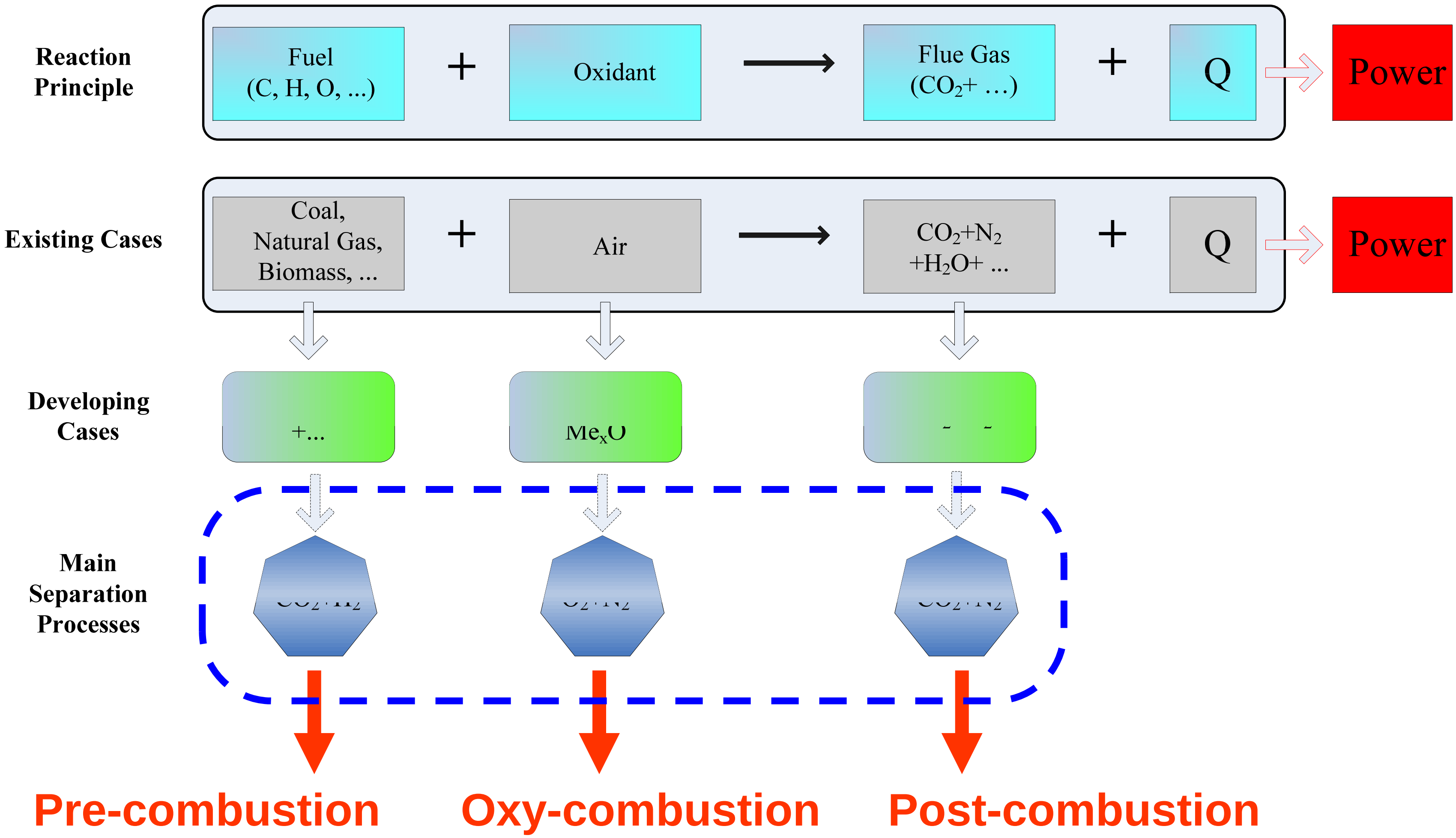
an important way to mitigate man-made CO2 emissions

**Reference: EIA, International Energy Outlook 2008*

BIGCCS: International CCS Research Centre (Trondheim, Norway)

- 400 mill NOK (65 mill USD) total in 8 years (2009-2016)
- 18 PhDs / 8 Post.docs (Coordinator: NTNU)
- 9 Industrial Partners
- 8 Research Institutes, 3 Universities
- Host Institution: SINTEF Energy Research

Ways to Capture CO2



Reaction Principle

Fuel (C, H, O, ...) + Oxidant ⟶ Flue Gas (CO_2+ …) + Q → Power

Existing Cases

Coal, Natural Gas, Biomass, ... + Air ⟶ CO_2+N_2 $+H_2O+$ ... + Q → Power

Developing Cases

+...

Me_xO

Main Separation Processes

Pre-combustion

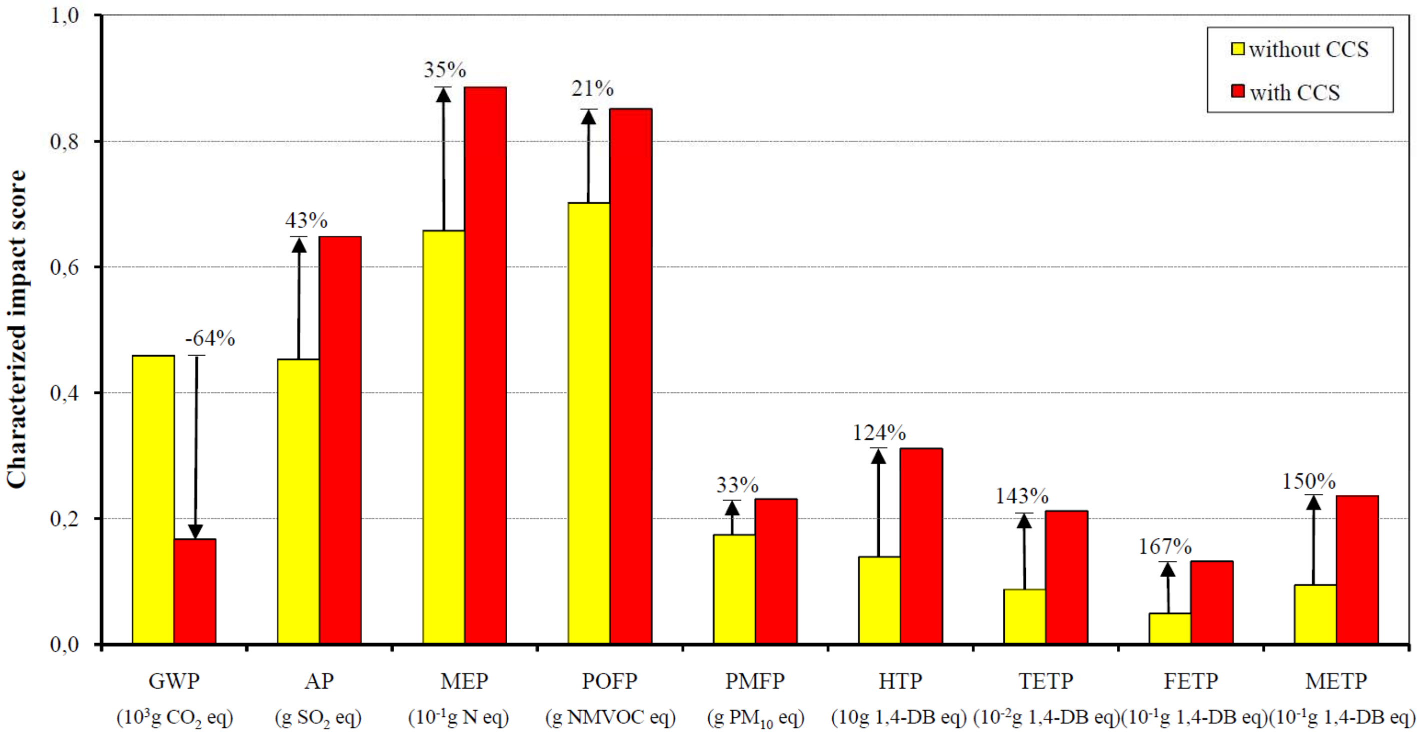
Oxy-combustion

Post-combustion

Why Oxy-Combustion for Coal based Power Plants?

- The reduction in power efficiency due to CO2 capture is less than for natural gas based power plants
- The increment of investment cost is less
- ⇒ A promising route to CO2 capture
- Opportunities for co-capture of SOx and NOx
- For Natural Gas: Oxy-combustion gas turbines represent a challenge

CCS and LCA



LCA of NGCC with post-combustion CCS

Notice: 90% CO2 capture = 64% reduction in GWP

Reference: Singh B., Strømman A. H., Hertwich E., 2010, Int. Jl. of Greenhouse Gas Control, in Press

Changes in Impact Potentials

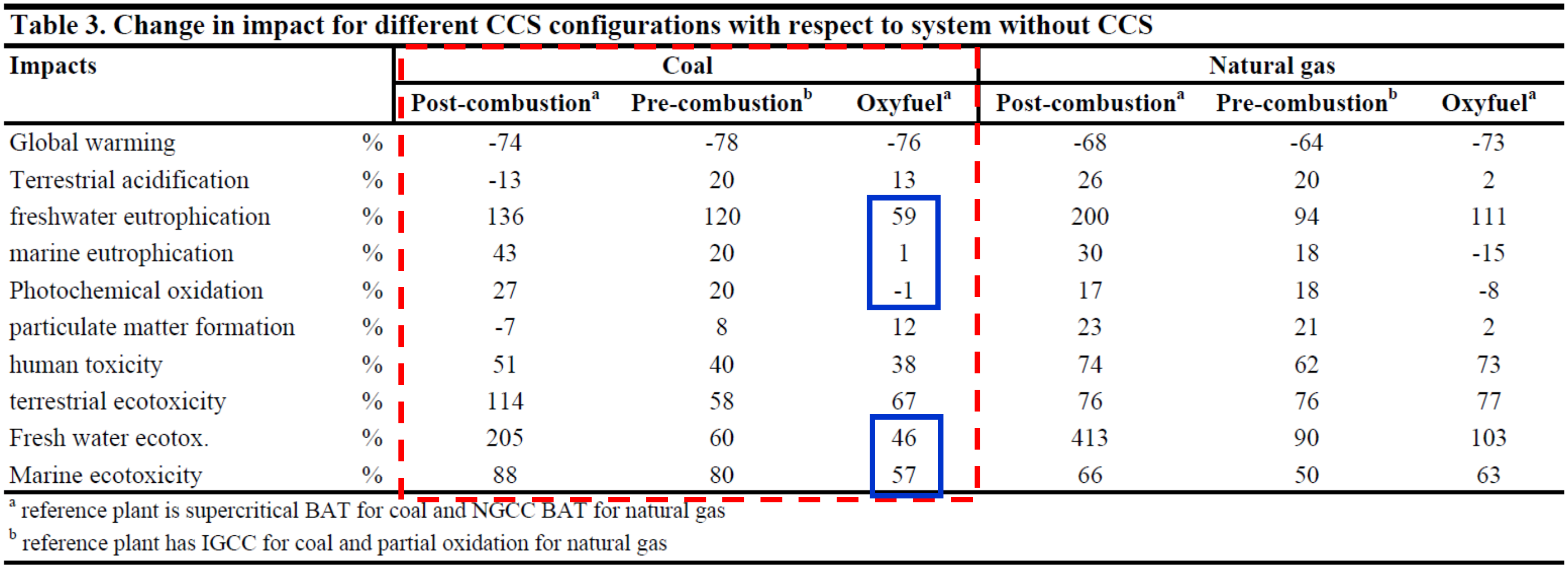


Table 3. Change in impact for different CCS configurations with respect to system without CCS

Impacts		Coal			Natural gas		
		Post-combustion[a]	Pre-combustion[b]	Oxyfuel[a]	Post-combustion[a]	Pre-combustion[b]	Oxyfuel[a]
Global warming	%	-74	-78	-76	-68	-64	-73
Terrestrial acidification	%	-13	20	13	26	20	2
freshwater eutrophication	%	136	120	59	200	94	111
marine eutrophication	%	43	20	1	30	18	-15
Photochemical oxidation	%	27	20	-1	17	18	-8
particulate matter formation	%	-7	8	12	23	21	2
human toxicity	%	51	40	38	74	62	73
terrestrial ecotoxicity	%	114	58	67	76	76	77
Fresh water ecotox.	%	205	60	46	413	90	103
Marine ecotoxicity	%	88	80	57	66	50	63

[a] reference plant is supercritical BAT for coal and NGCC BAT for natural gas

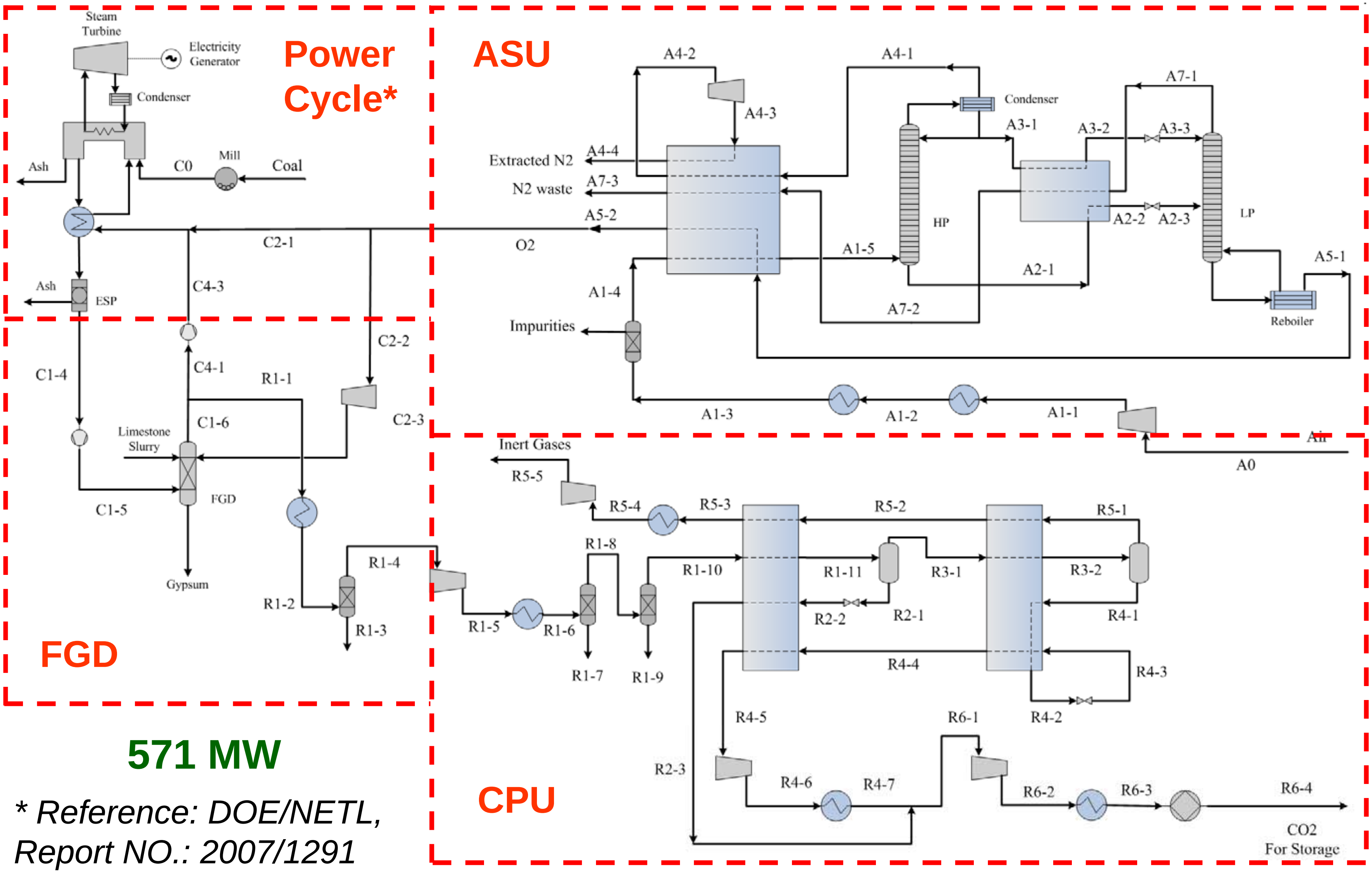
[b] reference plant has IGCC for coal and partial oxidation for natural gas

Notice: FEP, METP, POFP, FETP, METP are considerably less for oxy-combustion than for pre- and post- combustion, in particular for coal-fired power plants

Reference: Singh B., Strømman A. H., Hertwich E., 2010,
Int. Jl. of Greenhouse Gas Control, Submitted.

Power Plant

A Supercritical Oxy-Combustion Pulverized Coal Power Plant

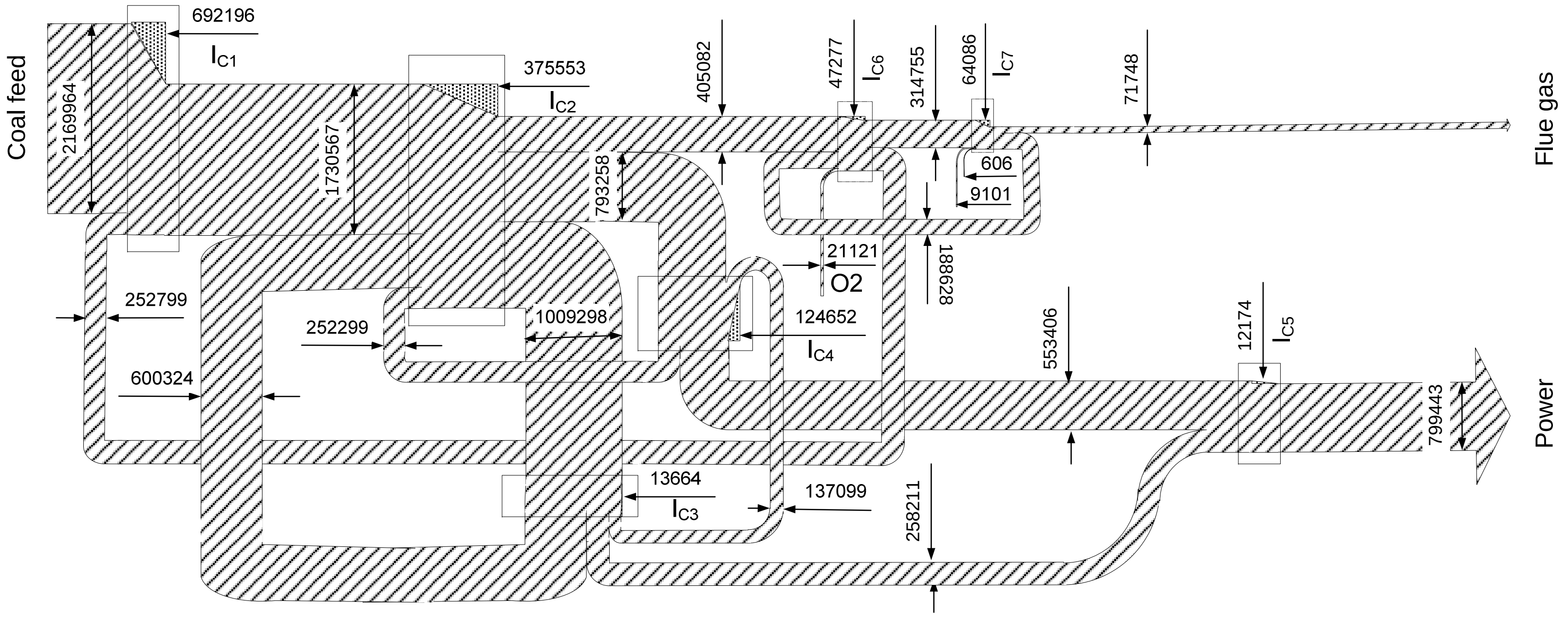


571 MW

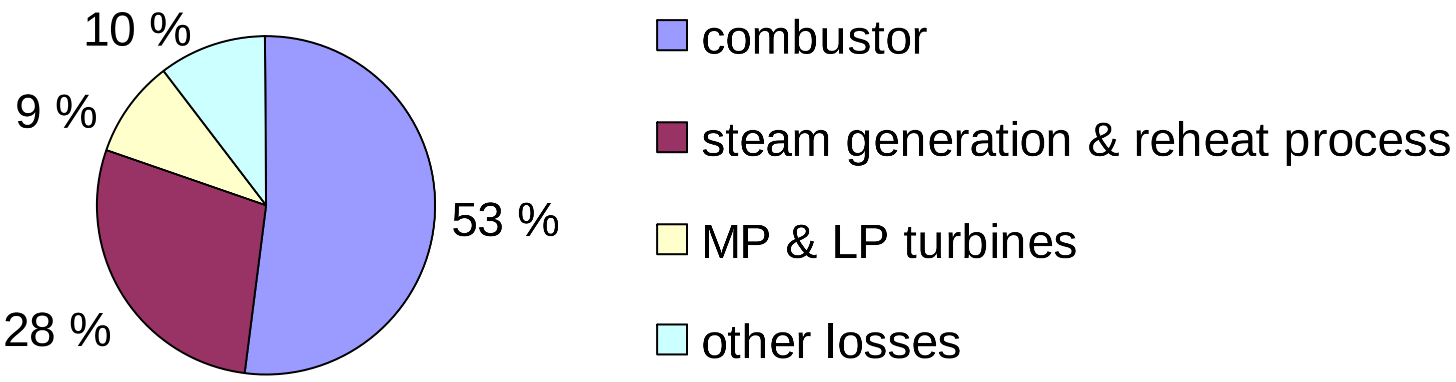
** Reference: DOE/NETL, Report NO.: 2007/1291*

Exergy Analysis

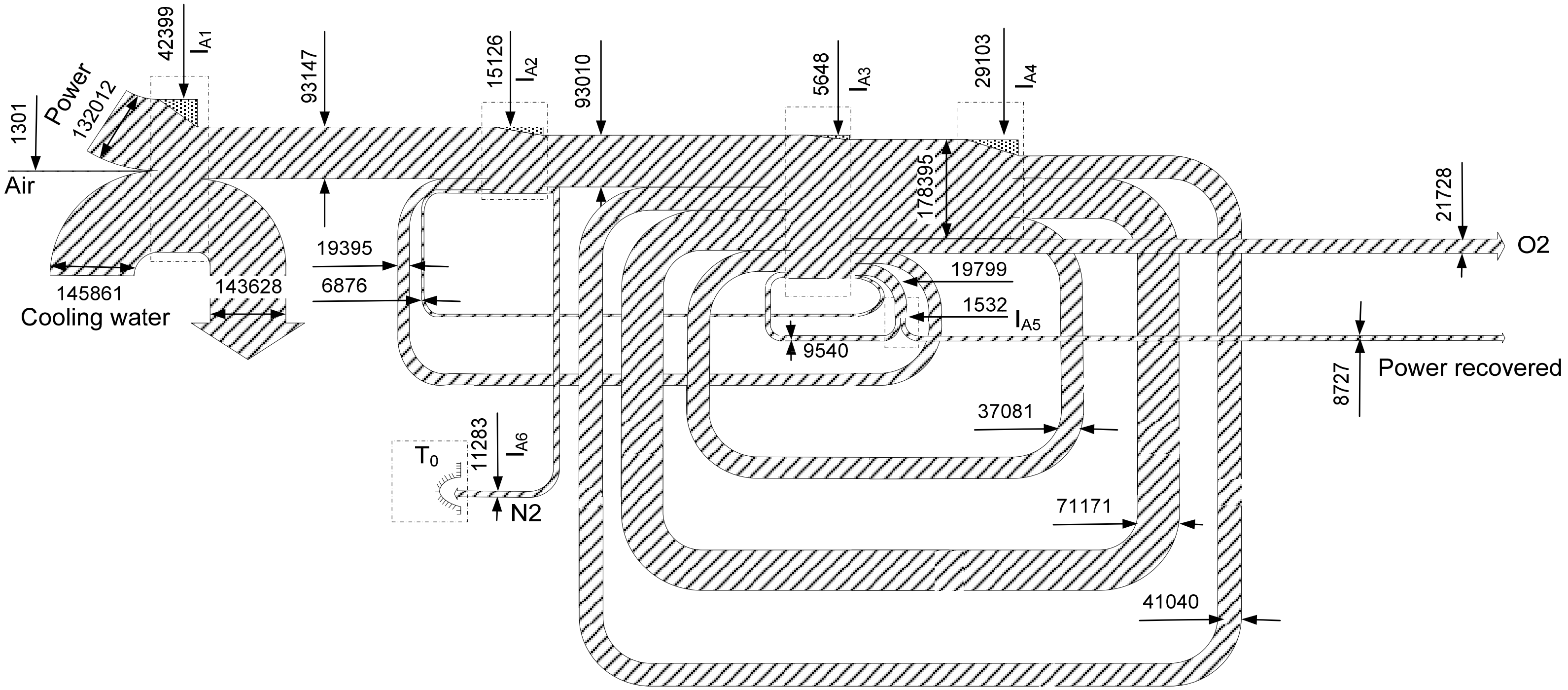
Exergy Flows in the Power Cycle



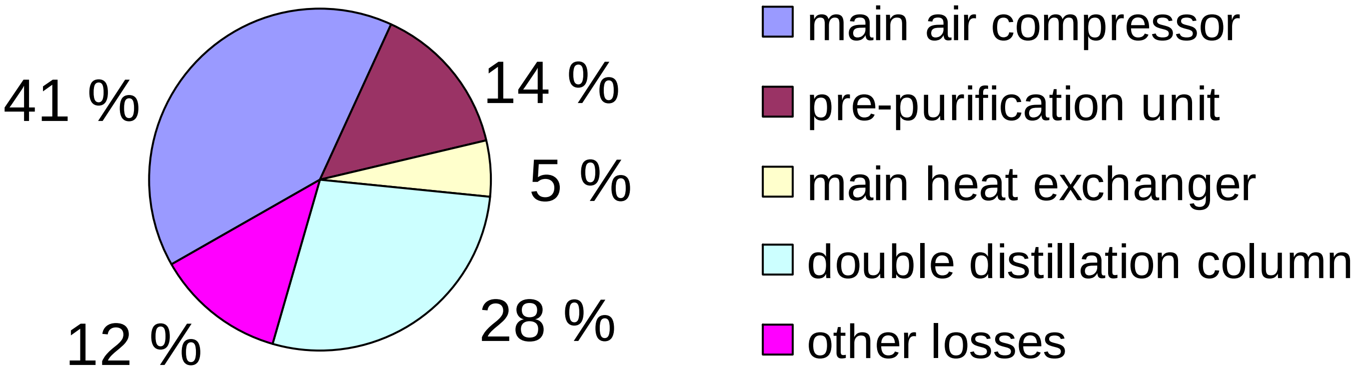
Distribution of Exergy Losses in the Power Cycle



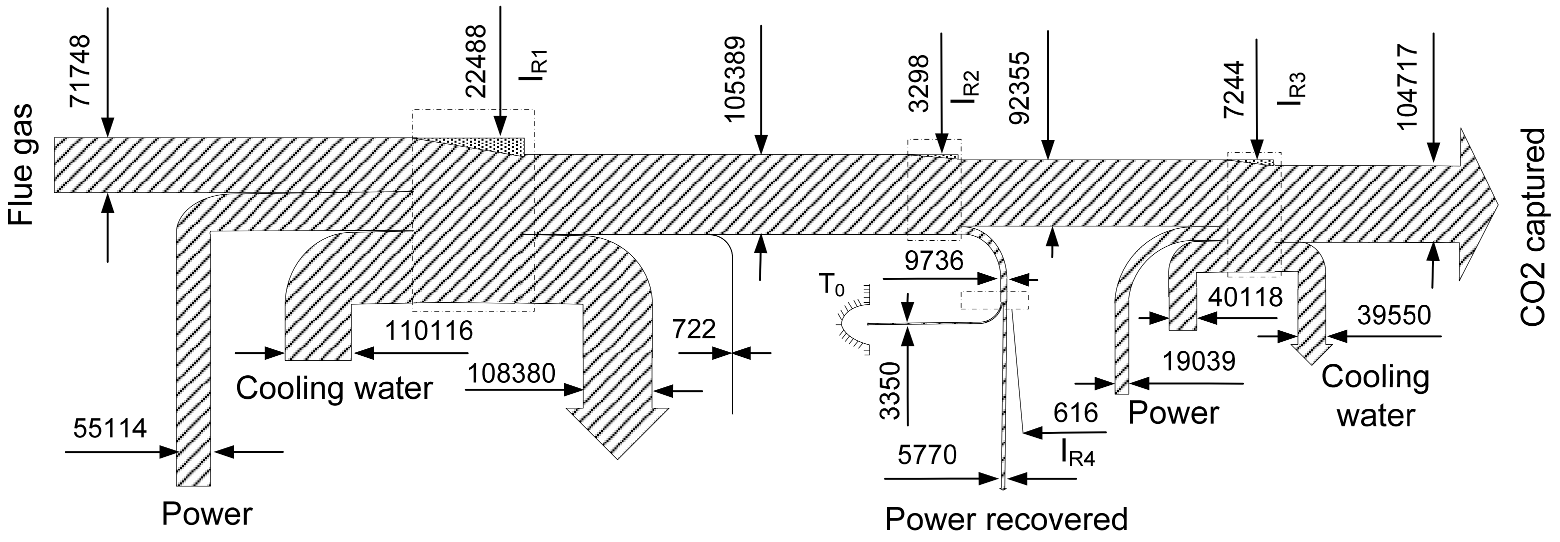
Exergy Flows in the ASU



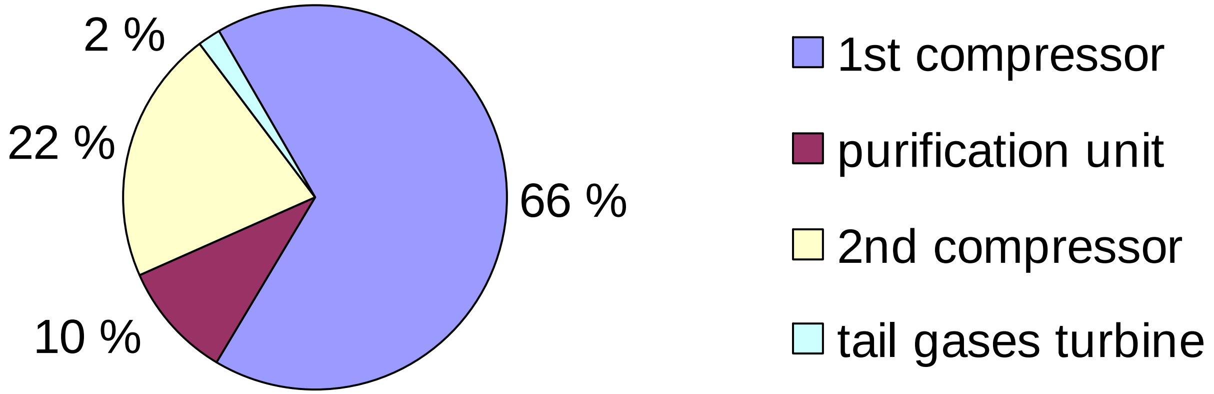
Distribution of Exergy Losses in the ASU



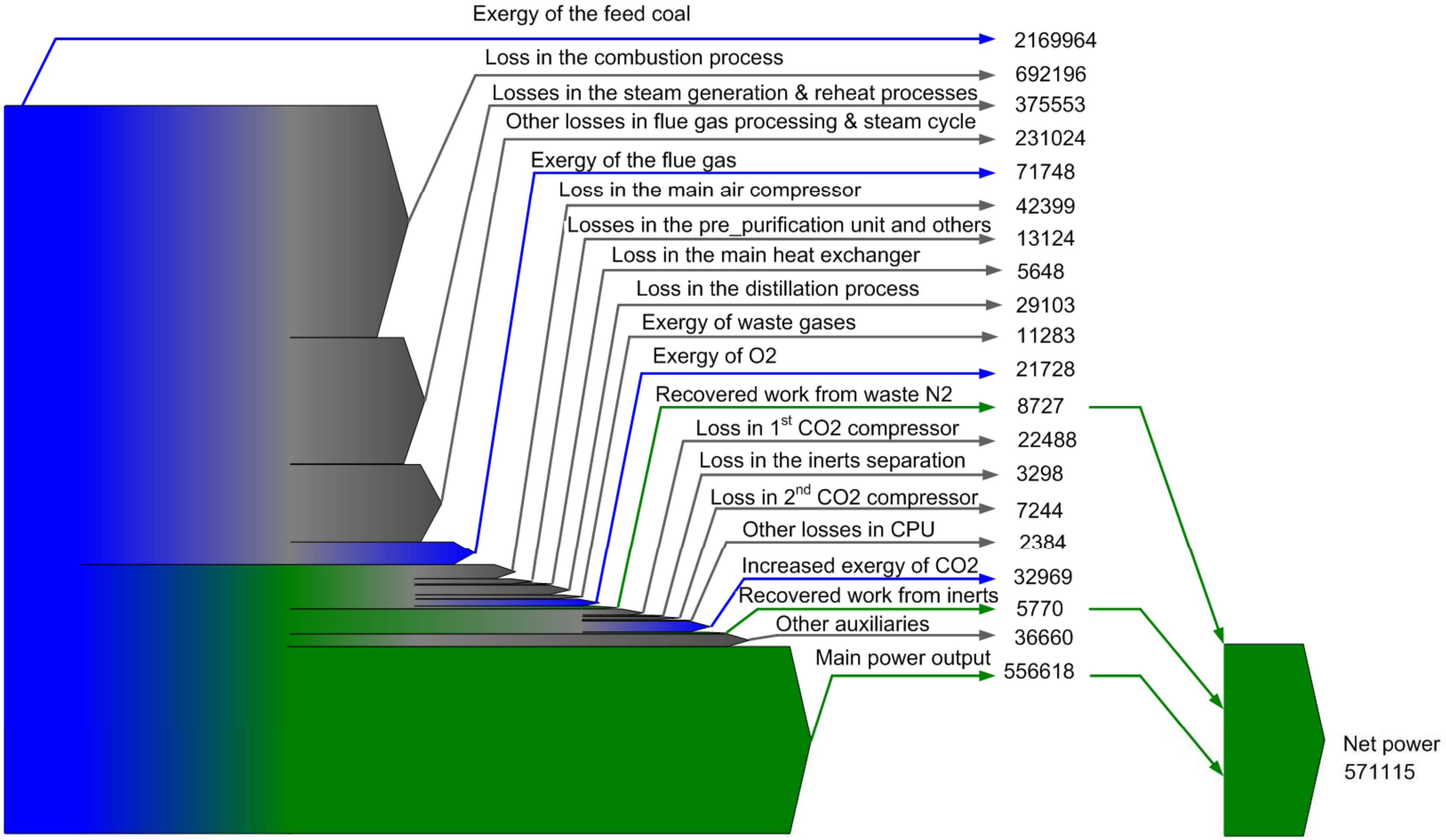
Exergy Flows in the CPU



Distribution of Exergy Losses in the CPU



Exergy Flows in the Entire Process



Net power output: 571,115 kW

Net power efficiency with CO2 capture: 30.4% (HHV)

Penalty Related to CO2 Capture

- Net power efficiency without CO2 capture: 40.6% (HHV)
- Efficiency penalty: 10.2% points

  caused by ASU: 6.6% points

  caused by CPU: 3.6% points
- Theoretical efficiency penalty: 3.4% points

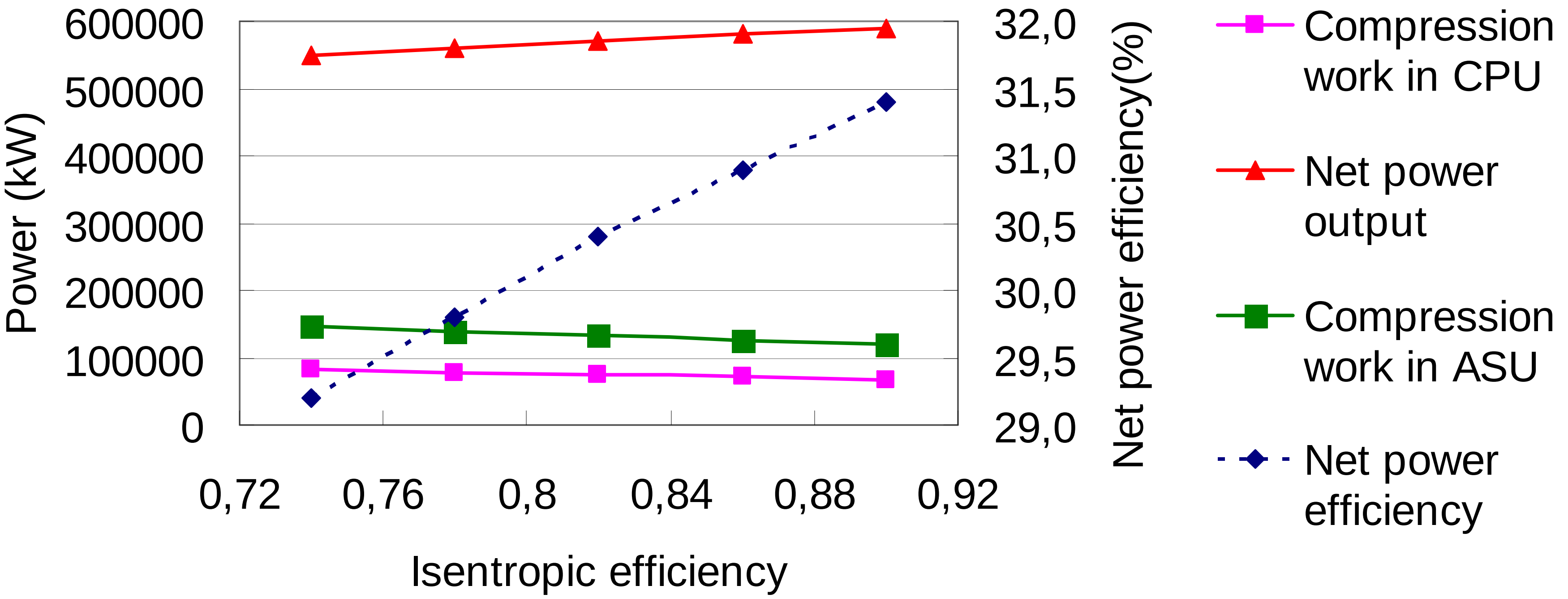
  caused by ASU: 1.4% points

  caused by CPU: 2.0% points

The ASU has the largest Potential for Improvement

Efficiency Improvements

Effects of Compressor Efficiencies



If the isentropic efficiencies of all compressors increase from 0.74 to 0.90:

- **the net power output increases from 549,024 kW to 589,243 kW**
- **the net power efficiency increases from 29.2 to 31.4% points**

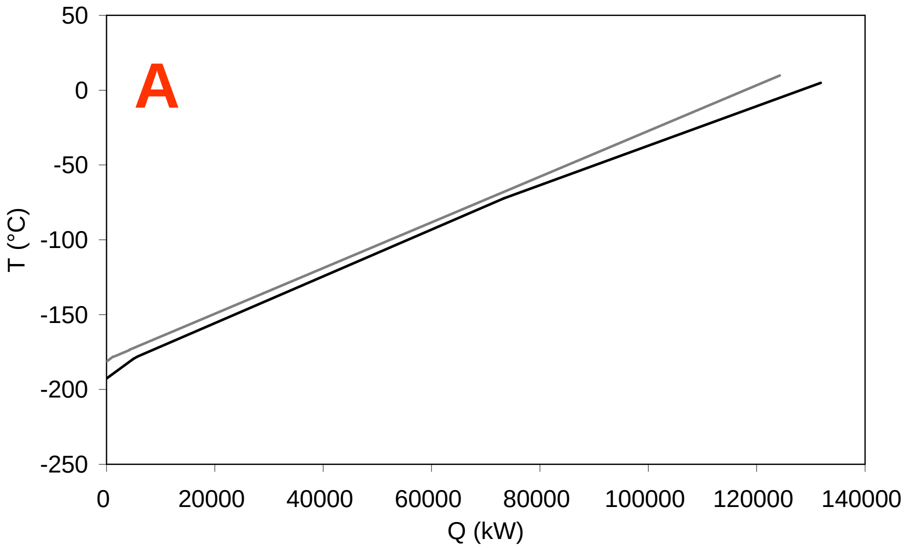
Effects of CO2 Recovery Rate

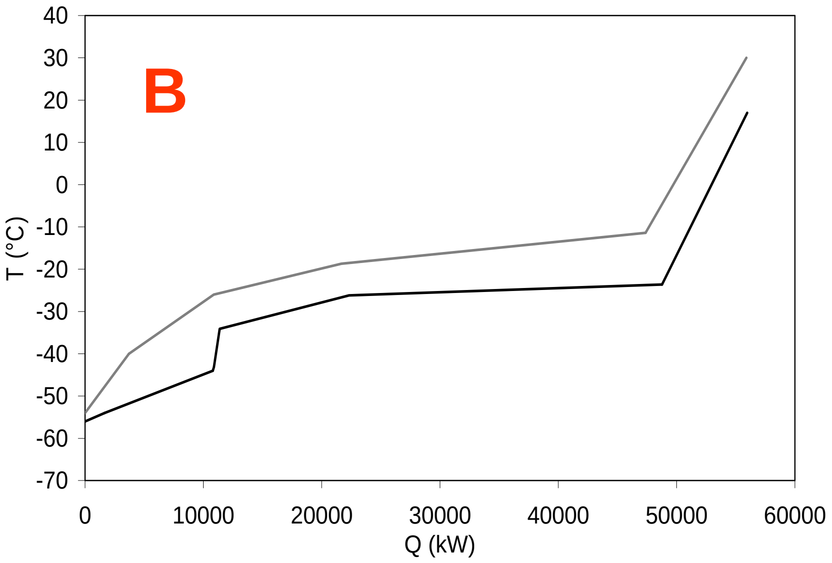
	Base Case	Case 1	Case 2	Case 3	Case 4
Operating pressure [bar]	32	25	20	18	15
CO_2 recovery rate [%]	95.1	93.3	91.5	90.2	86.9
Purity of capture CO_2 [mol%]	96.2	97.2	97.0	97.4	98.0
Power used in the CPU [kW]	68,383	66,902	63,4670	63,767	60,699
Net power output [kW]	571,115	572,597	576,029	575,731	578,799
Net power efficiency [%]	30.4	30.5	30.7	30.6	30.8

The net power efficiency increases from 30.4 to 30.7% points

if the CO2 recovery rate is reduced from 95.1% to 91.5%

Integration between ASU & CPU



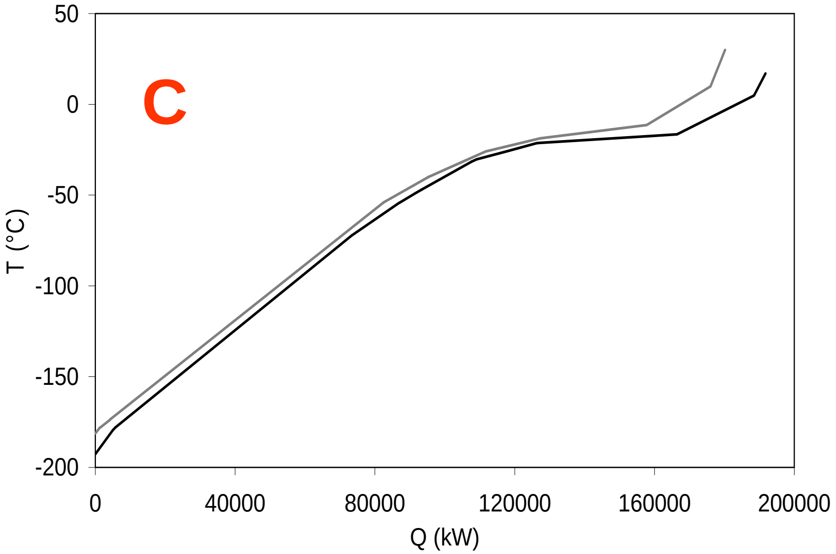


Composite curves for:

A - ASU,

B - CPU

C - integration between the ASU & CPU



The net power efficiency increases 0.2 % points

Conclusions

In Conclusion

- Oxy-combustion is more promising for coal-fired power plants than for natural gas based power plants
- The power efficiency penalty for CO2 capture is 10.2% points, while the theoretical penalty is 3.4% points
- The ASU and the CPU contribute 6.6% points and 3.6% points respectively
- The penalty can be mitigated by:
  1) Improving the performance of compressors
  2) Optimizing the CO2 recovery rate
  3) Heat integration between the ASU & the CPU

Thank You!

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