Potential for low-temperature capture technologies in different CCS applications

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Presentation outline

- Introduction and definitions
- Differences in capture conditions within different CCS applications
- Review of examples on application of low-temperature concepts for some of the capture conditions
  - Oxy-combustion: Flue gas separation
  - Pre-combustion: IGCC syngas separation
  - Post-combustion: CO_2 antisublimation from flue gas
- Discussion and concluding remarks

Cryogenic often used instead of low-temperature in literature, sometimes with a negative notion

“Use of **cryogenic processes** – is **only worth considering where there is a high concentration of CO_2** in the flue gas, as could be achieved in future IGCC designs. Cryogenic processes have the advantage of producing liquid CO_2 ready for transportation by pipeline”

Riemer P. Greenhouse gas mitigation technologies, an overview of the CO_2 capture, storage and future activities of the IEA Greenhouse Gas R&D programme, 37(6–8), 665–70 (1996).

“Cryogenic separation needs **too much energy** and appears to be **too expensive** […] In the end, **only physical and chemical (or mixed) absorption methods seem suitable** for large power plants…”

Kanniche, M. and C. Bouallou. CO_2 capture study in advanced integrated gasification combined cycle. Applied Thermal Engineering, 27(16), 2693–2702 (2007).

“The basic advantage of cryogenic processes is that, provided the CO_2 feed is properly conditioned, high recovery of CO_2 and other feed constituents is possible. This may also facilitate the final use or sequestering of CO_2. However, cryogenic processes are **inherently energy intensive**.”

Meisen, A, Shuai X. Research and development issues in CO_2 capture. Energy Conversion and Management, 38(1), S37–S42 (1997).

This, at least, does not apply to all capture conditions!

And, do we actually enter cryogenic temperatures?

Cryogenic vs. low-temperature, definitions and terminology

Generally inconsistent use of the term ‘cryogenic’ in literature

Cryogenic temperatures:

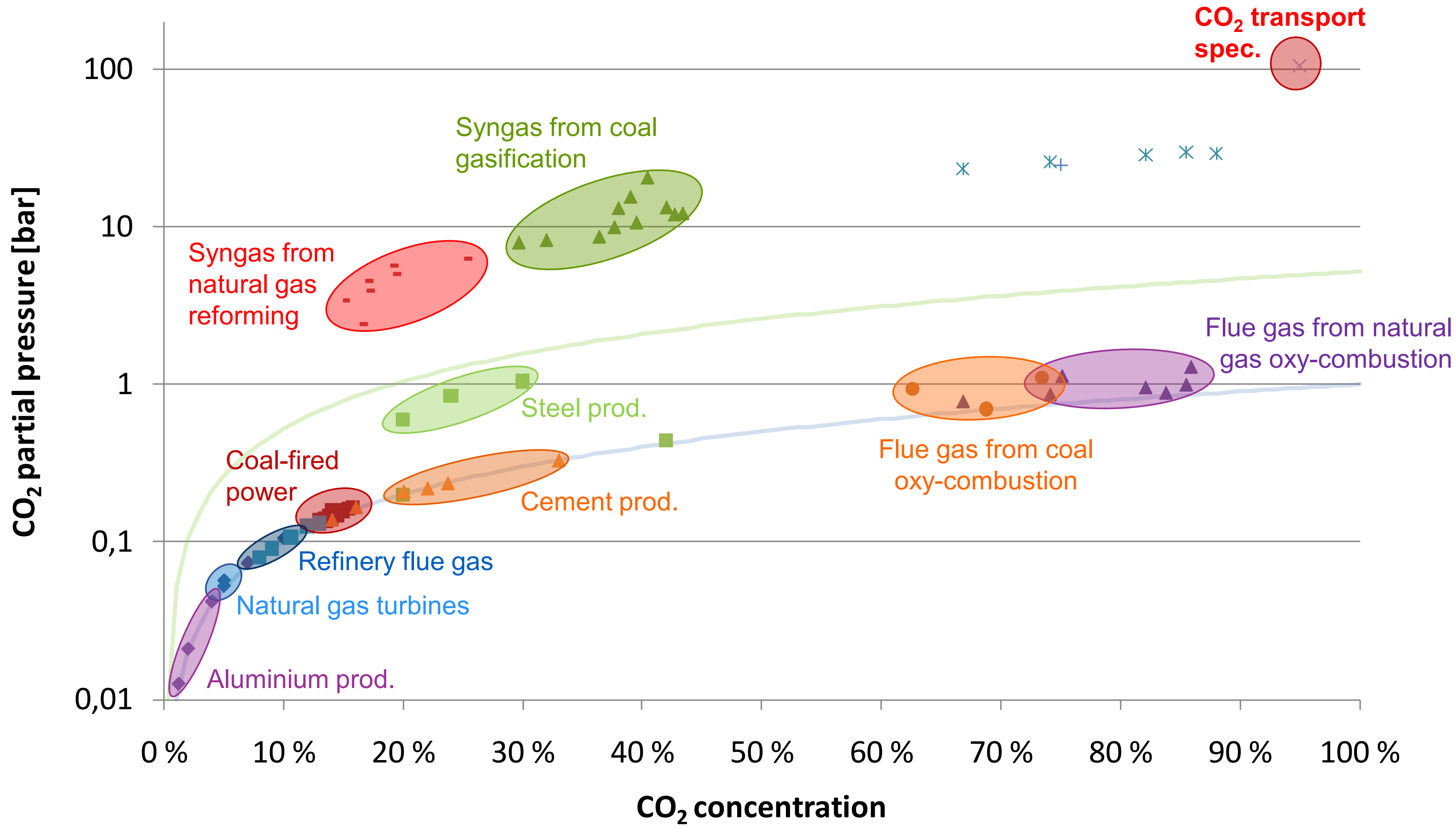
- Common scientific definition: Temperatures below -153°C (120 K) IIR Int Dict

Important to distinguish between ‘cryogenic’ and ’low-temperature’

Low-temperature CO_2 capture:

- Temperatures below 0°C
- Liquid phase separation, temp above the CO_2 triple point temp ($\geq$ -56°C)
  - Applied to flue gas and synthesis gas above CO_2 triple point pressure (5.2 bar)
  - Implies condensation of CO_2 without the use of circulating solvents/chemicals
  - Separation of CO_2-rich liquid phase from non-condensables (N_2, O_2, Ar, H_2 etc.)
  - CO_2 in liquid phase, pressurisation by pumping instead of multi-stage gas compression
- Solid phase sep, below the CO_2 triple p. temp (< -56°C) but above -120°C
  - Implies antisublimation / freeze-out of CO_2 as solids from non-condensables
  - Can be applied to flue gas at pressures below CO_2 triple point pressure (5.2 bar)

CO_2 capture conditions



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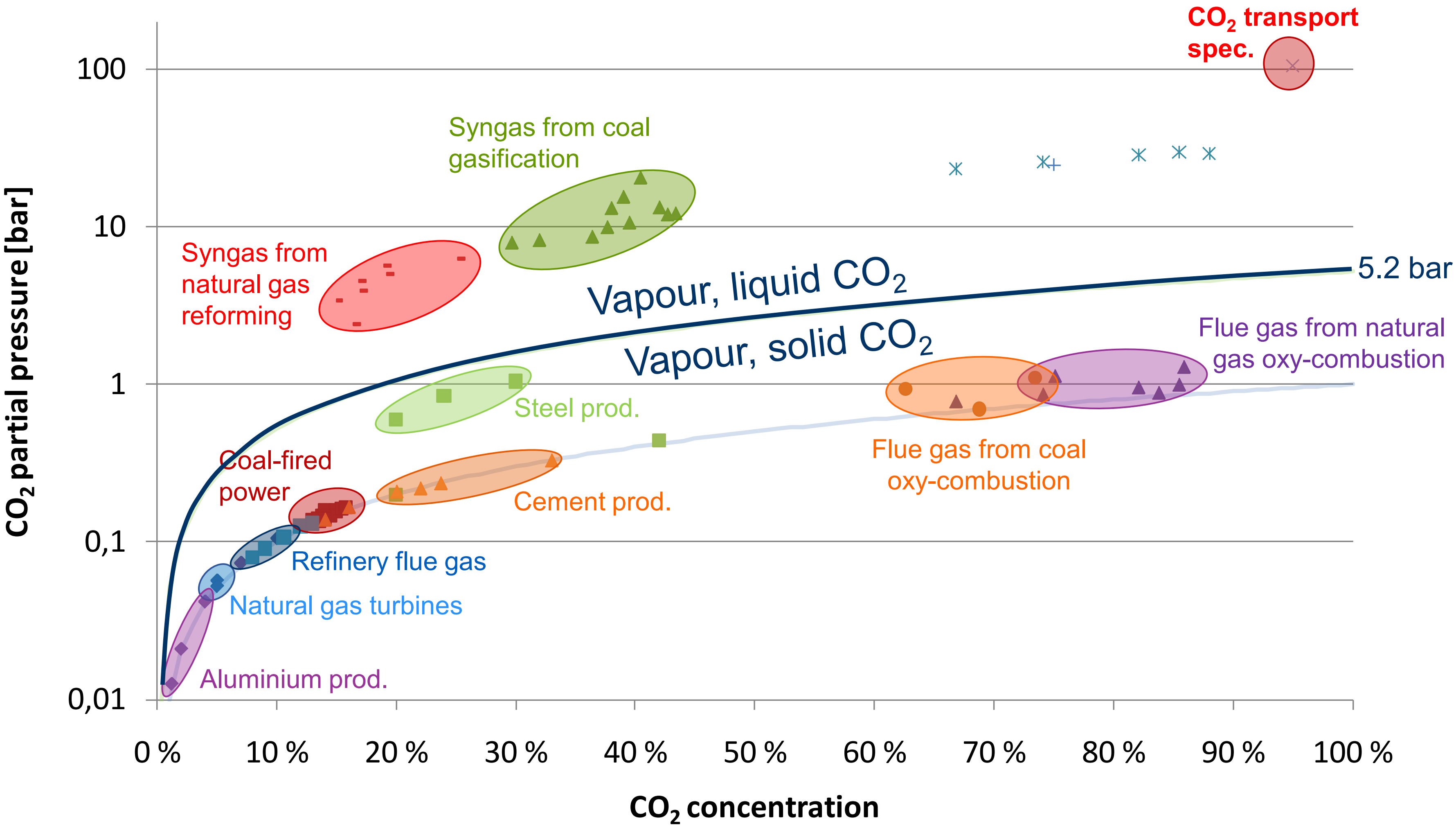

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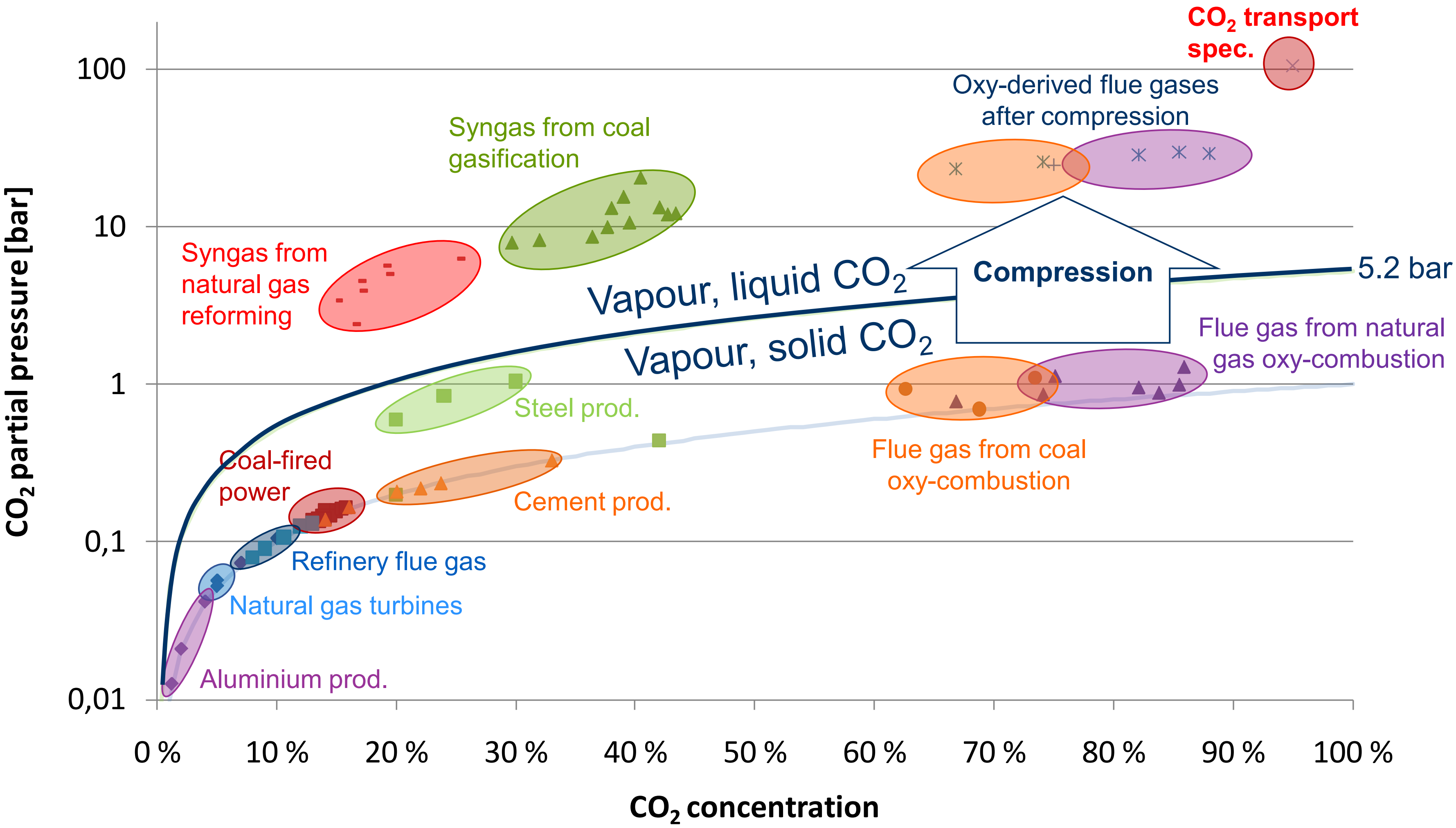
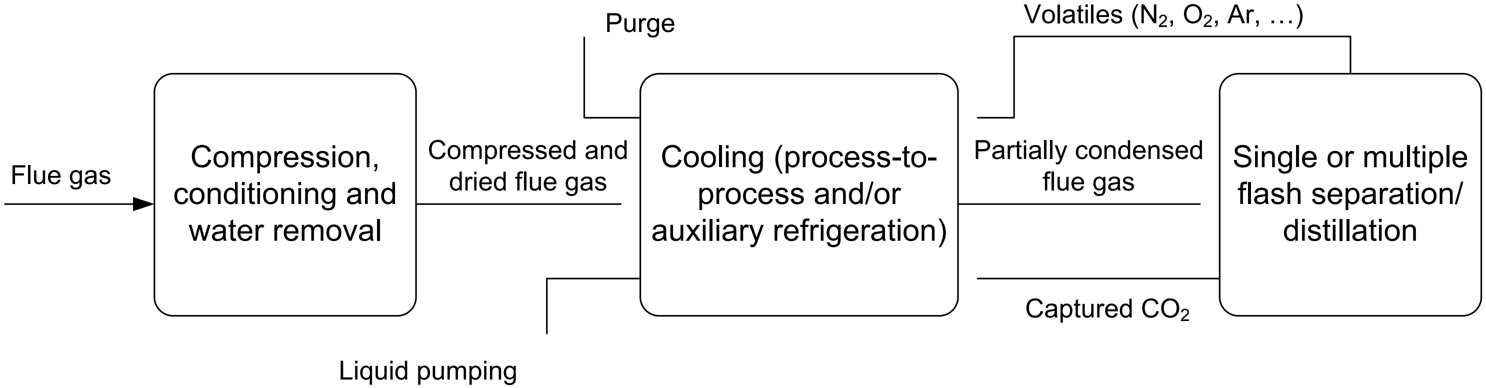


Oxy-combustion CO_2 capture



Flue gas

Compression, conditioning and water removal

Compressed and dried flue gas

Purge

Cooling (process-to-process and/or auxiliary refrigeration)

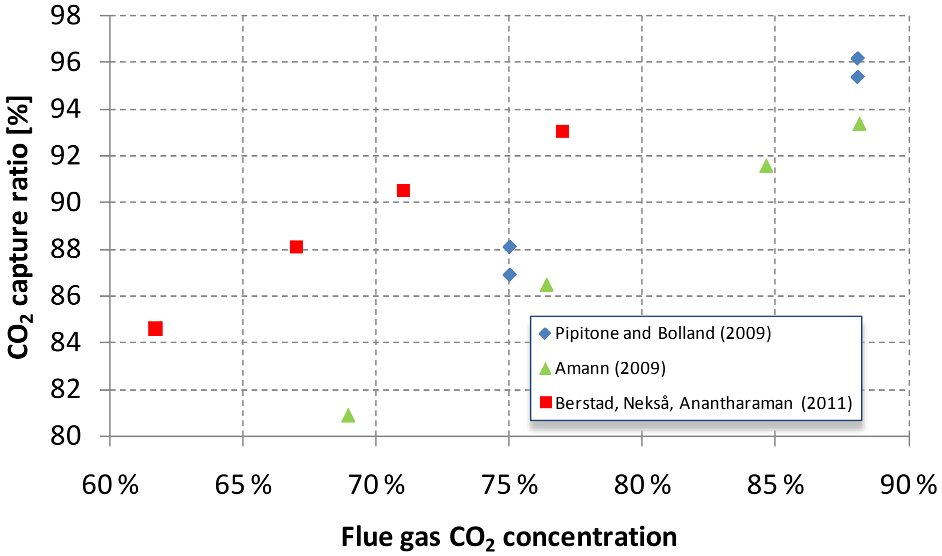
Liquid pumping

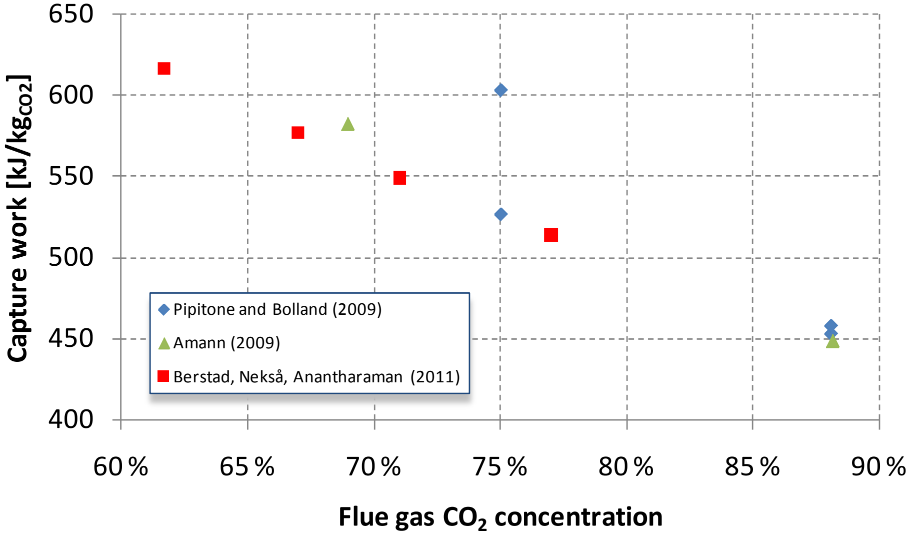
Volatiles (N_2, O_2, Ar, …)

Partially condensed flue gas

Single or multiple flash separation/ distillation

Captured CO_2





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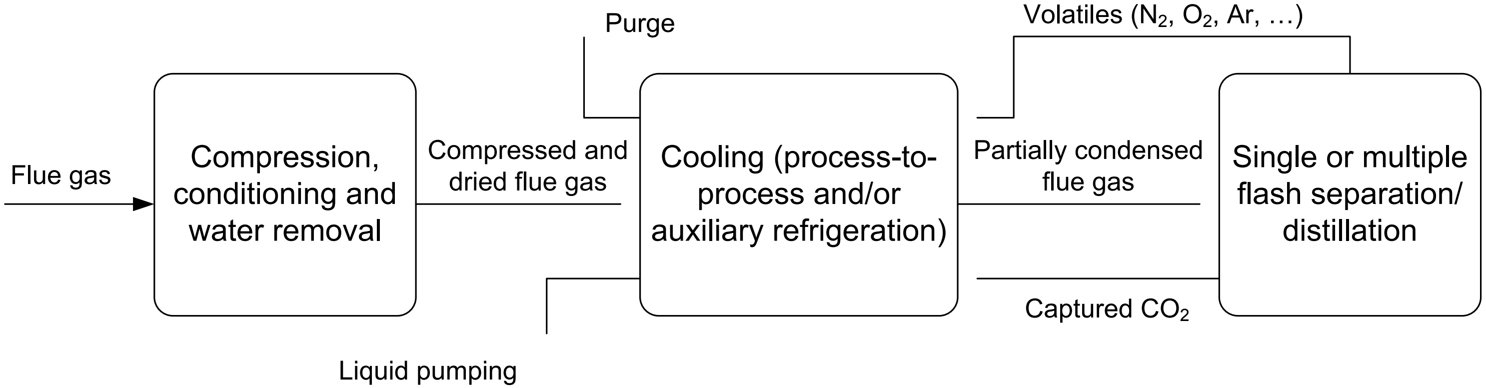

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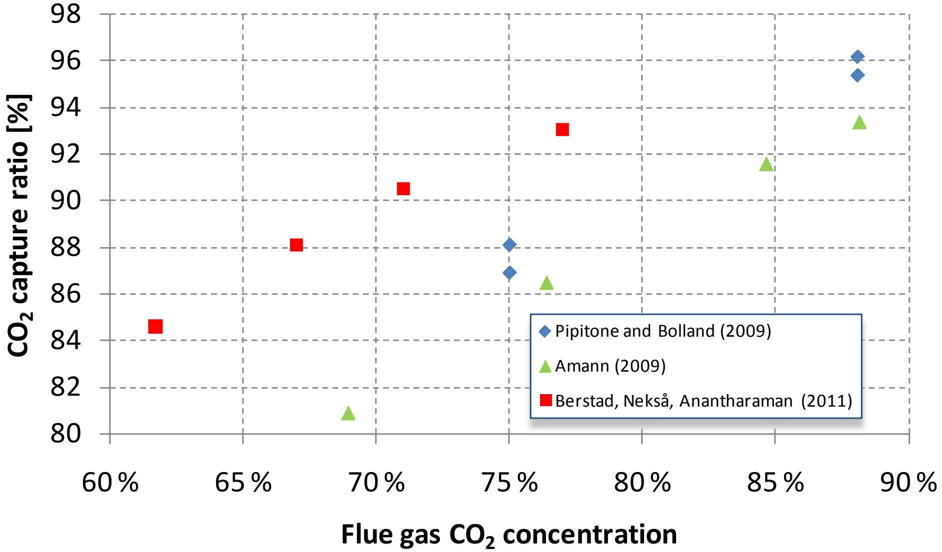

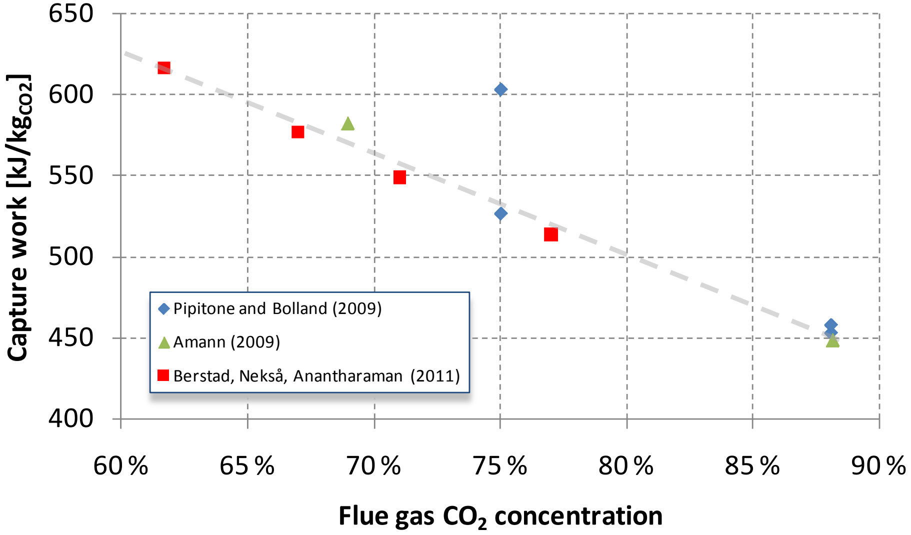

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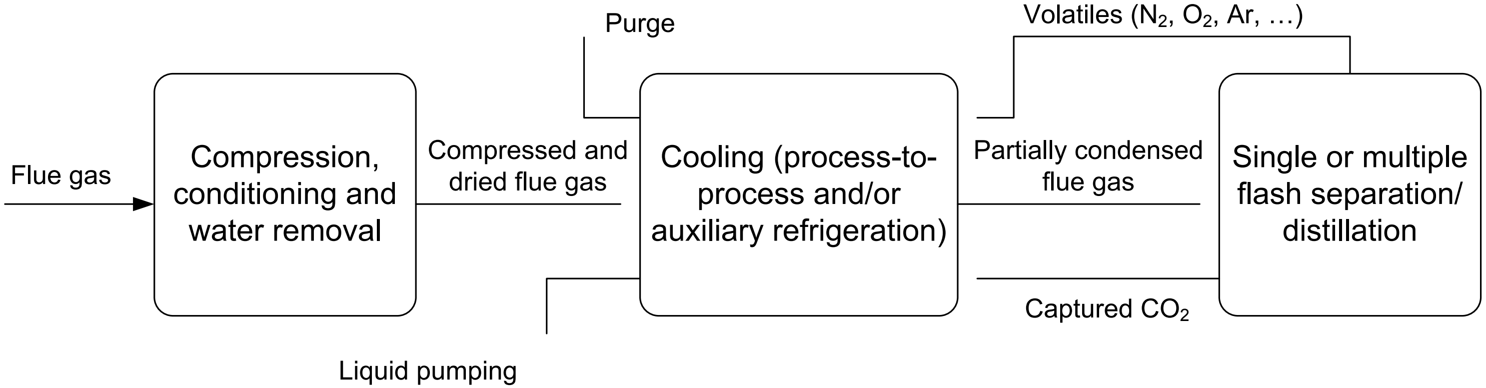

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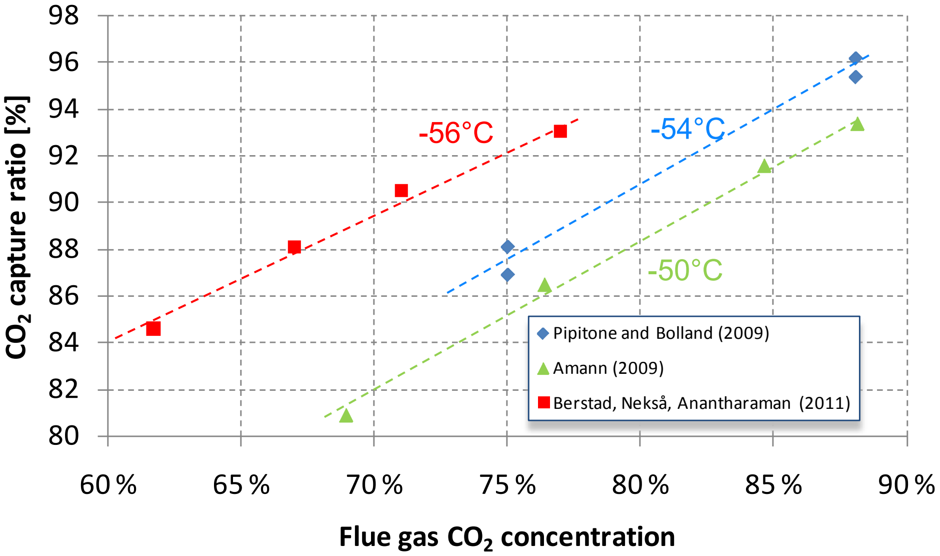

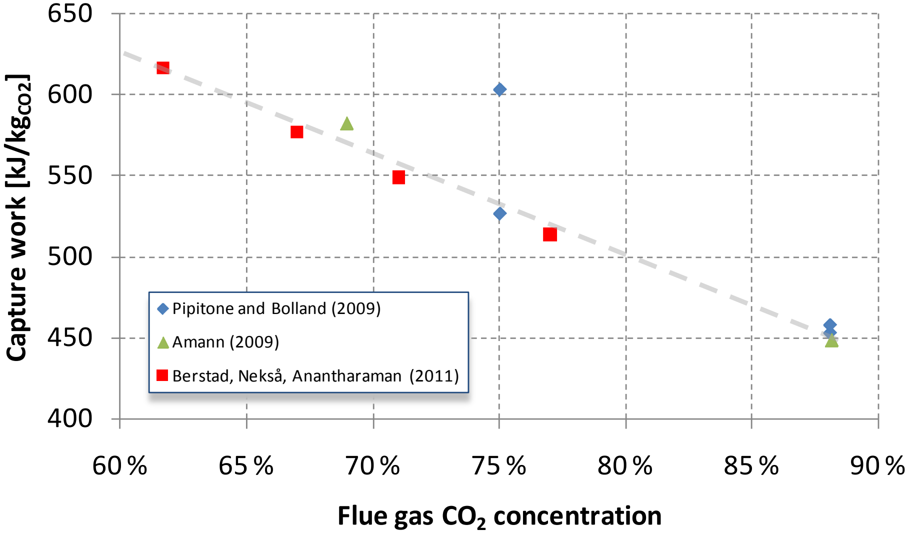

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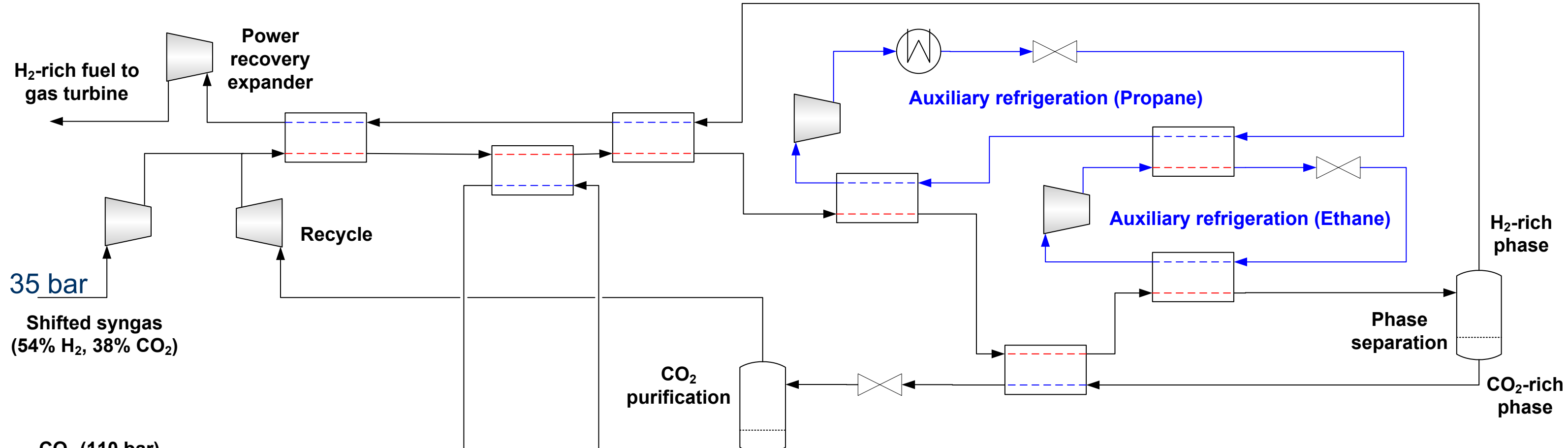
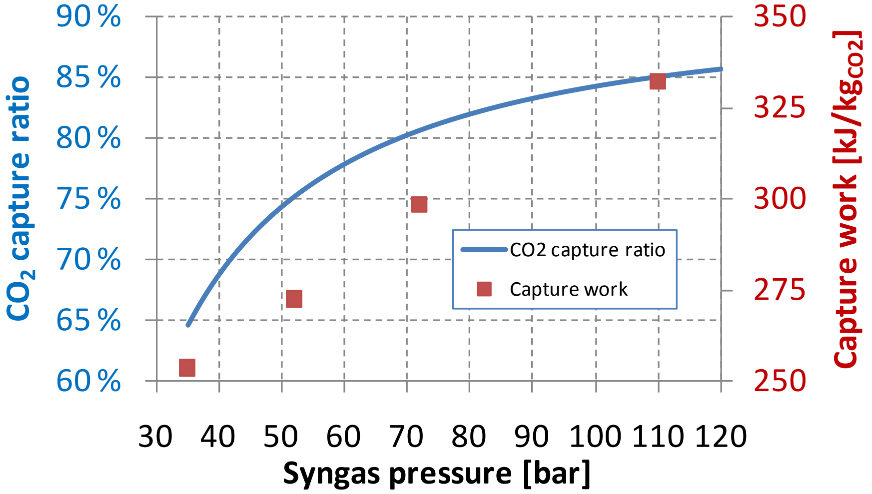
Syngas from coal gasification (IGCC)



Isentropic eff. syngas compressor	%	82
Isentropic eff. propane/ethane compressors	%	82
Isentropic eff. recycle compressor	%	80
Isentropic eff. power recovery expander	%	85
Eff. liquid CO_2 pump	%	80
Δ*P* per heat exchanger	bar	0.2
Δ*P* inter- and after-coolers	bar	0.5
Minimum approach *T* in heat exchangers	C	3
Δ*T* in propane–ethane cascade heat exchanger	C	5



Should be competitive with physical solvents

Berstad D, Nekså P, Anantharaman R. CO_2 capture from IGCC by low-temperature syngas separation and partial condensation of CO_2. TCCS-6 (2011)

Post-combustion capture by antisublimation (Clodic et al., 2005)

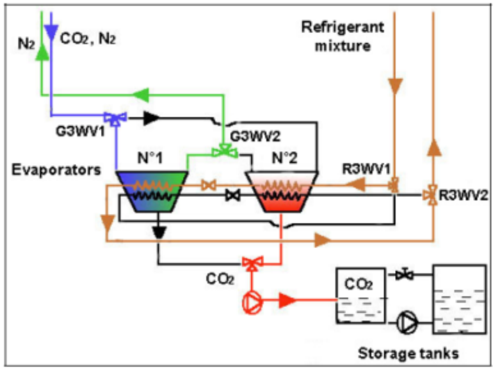
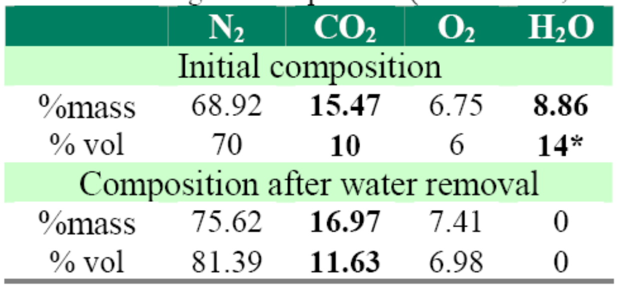


Fig. 2: Layout of the CO_2 capture system (Clodic and Younes, 2002)

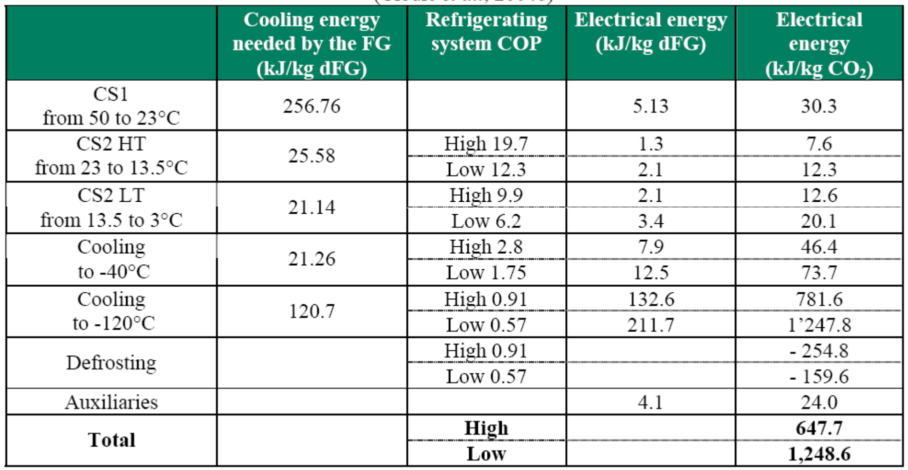
Table 2 Boiler flue gases composition (Clodic *et al.*, 2004b)



	N_2	CO_2	O_2	H_2O
Initial composition				
%mass	68.92	**15.47**	6.75	**8.86**
% vol	70	**10**	6	**14***
Composition after water removal				
%mass	75.62	**16.97**	7.41	0
% vol	81.39	**11.63**	6.98	0

**The high water content is due after-treatment systems typically used on a boiler flue gases*

Table 3 Summary of the cooling and electrical energies needed for CO_2 capture by anti-sublimation (Clodic *et al.*, 2004b)



	Cooling energy needed by the FG (kJ/kg dFG)	Refrigerating system COP	Electrical energy (kJ/kg dFG)	Electrical energy (kJ/kg CO_2)
CS1 from 50 to 23°C	256.76		5.13	30.3
CS2 HT from 23 to 13.5°C	25.58	High 19.7	1.3	7.6
		Low 12.3	2.1	12.3
CS2 LT from 13.5 to 3°C	21.14	High 9.9	2.1	12.6
		Low 6.2	3.4	20.1
Cooling to -40°C	21.26	High 2.8	7.9	46.4
		Low 1.75	12.5	73.7
Cooling to -120°C	120.7	High 0.91	132.6	781.6
		Low 0.57	211.7	1’247.8
Defrosting		High 0.91		- 254.8
		Low 0.57		- 159.6
Auxiliaries			4.1	24.0
Total		**High**		**647.7**
		Low		**1,248.6**

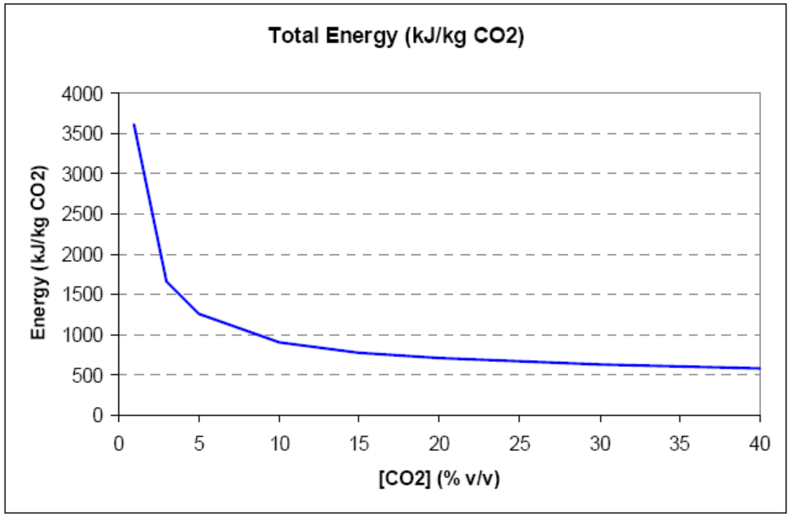
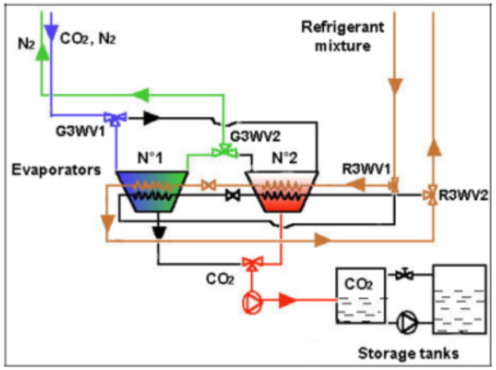


Fig. 7: Energy consumption function of the CO_2 concentration for a 90% CO_2 capture efficienc
(Younes, 2003b)

Clodic D et al. CO_2 capture by anti-sublimation .Thermo-economic process evaluation. 4th Annual Conference on Carbon Capture & Sequestration, May 2–5, 2005, Alexandria (VA), USA.

Post-combustion capture by antisublimation (Clodic et al., 2005)



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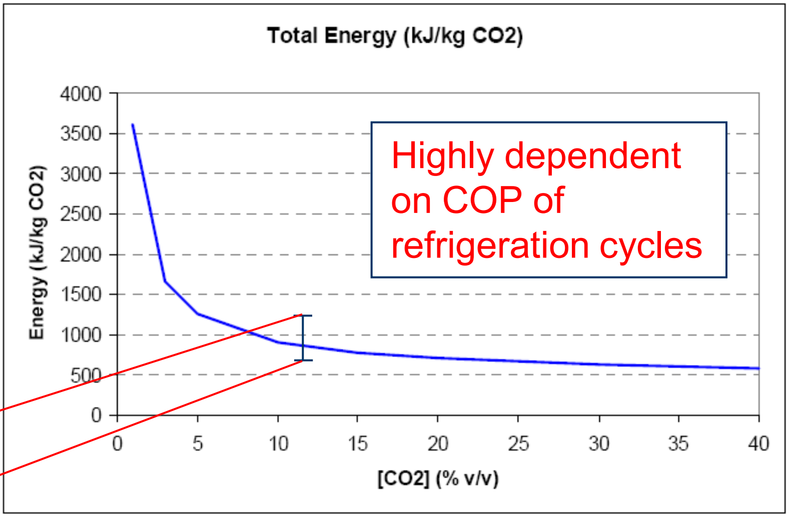

Highly dependent on COP of refrigeration cycles

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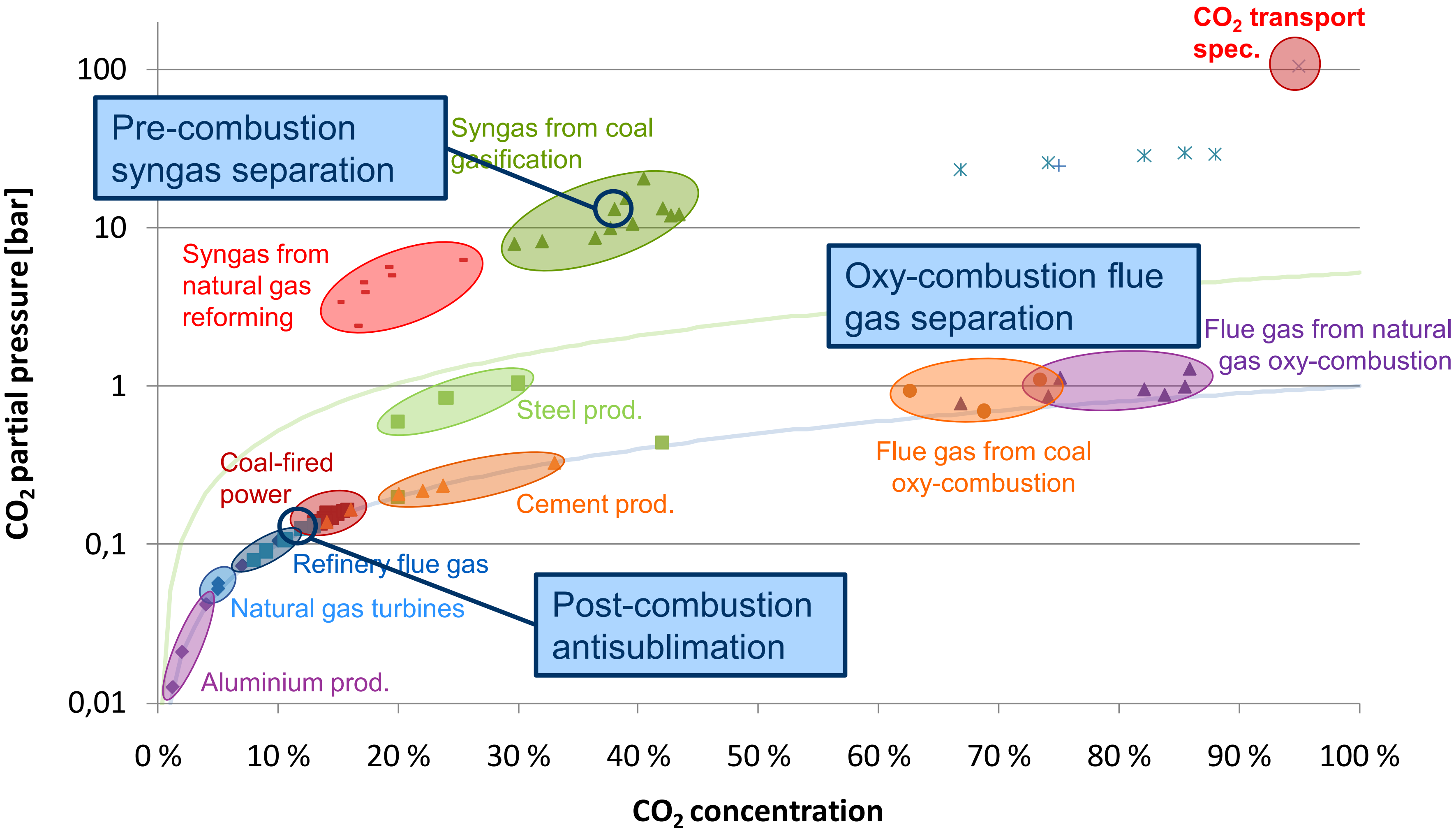
Summary



Pre-combustion syngas separation

Oxy-combustion flue gas separation

Post-combustion antisublimation

Conclusions

- Substantial difference in CO_2 capture conditions with respect to concentrations and pressure.
- Low-temperature capture technologies can in principle be applied for most of these conditions
- For certain applications, conceptual studies indicate competitive energy performance
- To obtain a complete benchmarking between low-temperature and baseline technologies, global simulations, with equalised boundary conditions and detail levels, must be performed
- Finally, techno-economic comparisons based on realistic cost data for full-scale processes must be carried out

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