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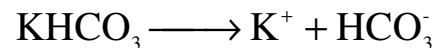
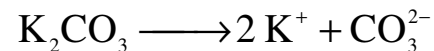
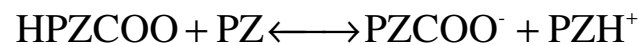
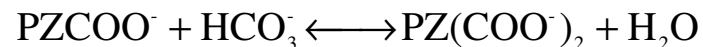
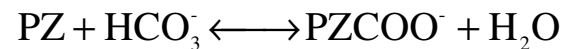
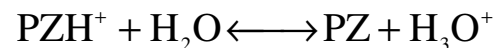
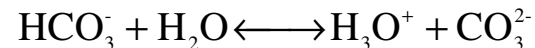
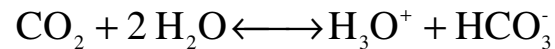
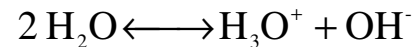
# **Evaluation of Post-Combustion CO<sub>2</sub>-Capture using Piperazine- Promoted Potassium Carbonate in a Coal Fired Power Station**

11<sup>th</sup> Workshop of the Post-Combustion CO<sub>2</sub>-Capture Network  
Vienna, 21<sup>st</sup> May 2008

- **CO<sub>2</sub>-Capture with K<sub>2</sub>CO<sub>3</sub>/PZ**
  - Thermodynamic model
  - Boundary conditions
- **CO<sub>2</sub>-Compression**
- **Power Plant Integration**
- **Results**
  - Specific reboiler heat duty
  - Specific power loss of overall integrated process
- **Column Design**
  - Absorber and desorber sizes
- **Comparison to MEA**
- **Summary and Outlook**

- **CO<sub>2</sub>-capture process with MEA is considered the reference in post-combustion CO<sub>2</sub>-capture, as**
  - Experience from commercial processes exist
  - Drawbacks: corrosivity, degradation and large regeneration heat duty
- **Potassium Carbonate (K<sub>2</sub>CO<sub>3</sub>)**
  - Cheap
  - Non-volatile
  - Non-toxic
  - But: low rate of absorption at atmospheric pressure
- **Promotion with Piperazine (PZ)**
  - Two amine functional groups ⇒ large capacity + high rate of absorption
  - Less sensitive towards O<sub>2</sub>, SO<sub>x</sub> and NO<sub>x</sub> than MEA

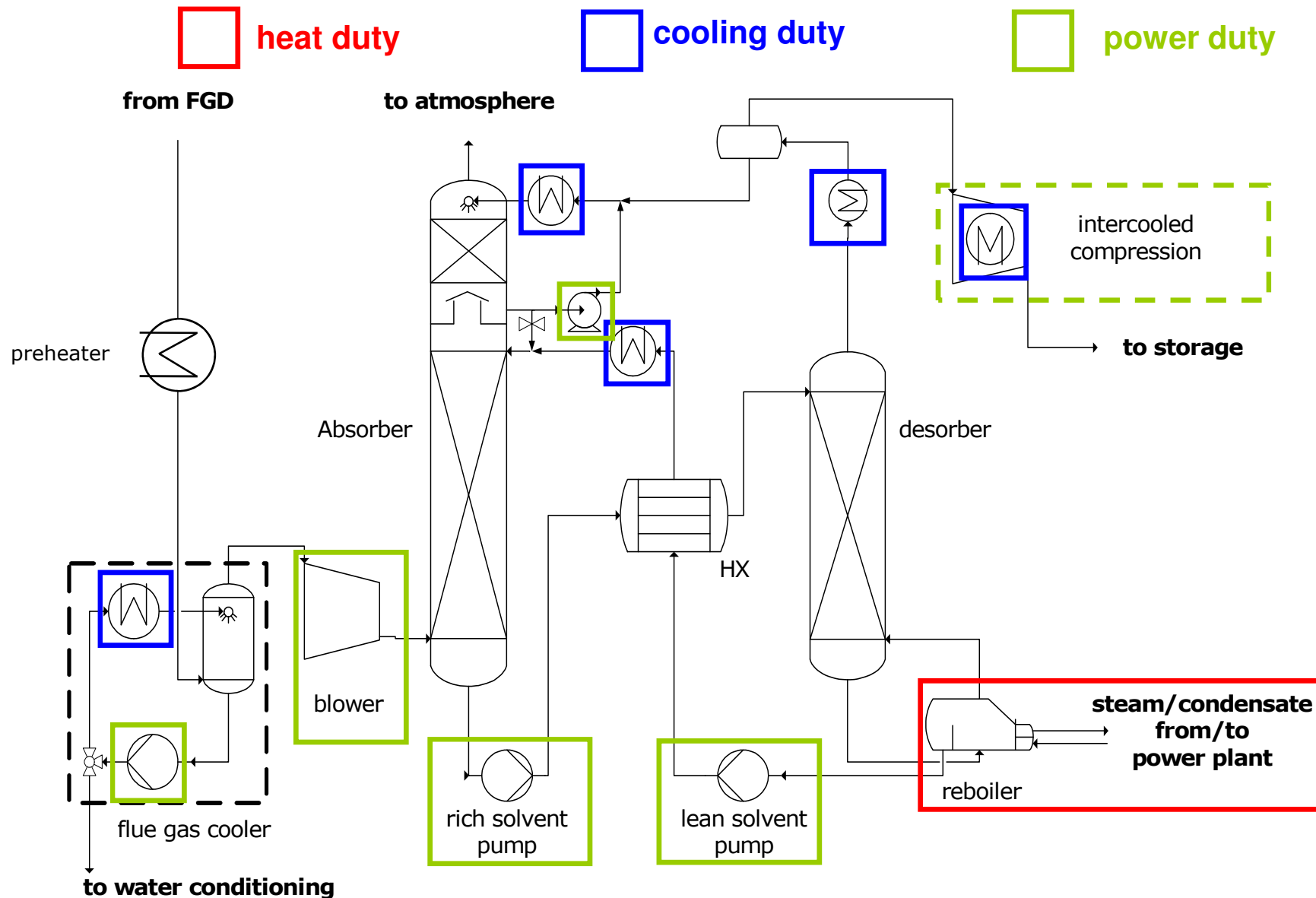
- Chemical absorption of CO<sub>2</sub> with K<sub>2</sub>CO<sub>3</sub>/PZ described by reaction scheme:



**rate of  
absorption**

- Carbamate reactions dominant for overall absorption rate
- Electrolyte Non Randomness Two Liquid Model (eNRTL) in ASPEN Plus
- eNRTL parameters regressed by *Hilliard (2007)*

# Interfaces to Power Plant



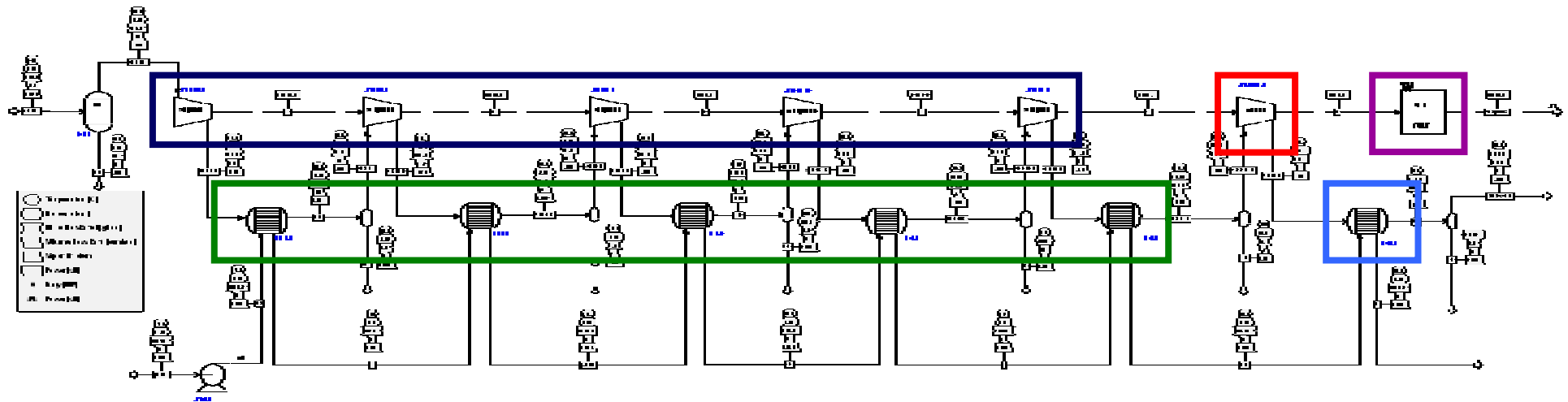
# Boundary Conditions

- Flue gas mass flow 577 kg / s
- Flue gas temperature from FGD 47 °C
- Flue gas temperature at absorber inlet 62 °C
- Flue gas CO<sub>2</sub> concentration 14.2 vol% (wet)  
15.9 vol% (dry)
- Absorber solvent inlet temperature 40 °C
- Lean-rich heat exchanger LMTD 5 K
- Reboiler temperature difference 10 K
- CO<sub>2</sub> condition at compressor outlet 40 °C / 110 bara
- Analysed solvents 2.5 m K<sub>2</sub>CO<sub>3</sub> / 2.5 m PZ (S<sub>2.5,2.5</sub>)  
3.2 m K<sub>2</sub>CO<sub>3</sub> / 1.6 m PZ (S<sub>3.2,1.6</sub>)  
4.8 m K<sub>2</sub>CO<sub>3</sub> / 0.6 m PZ (S<sub>4.8,0.6</sub>)  
3.0 m K<sub>2</sub>CO<sub>3</sub> (S<sub>3.0</sub>)
- Lean Loading *varied for minimisation of reboiler duty*

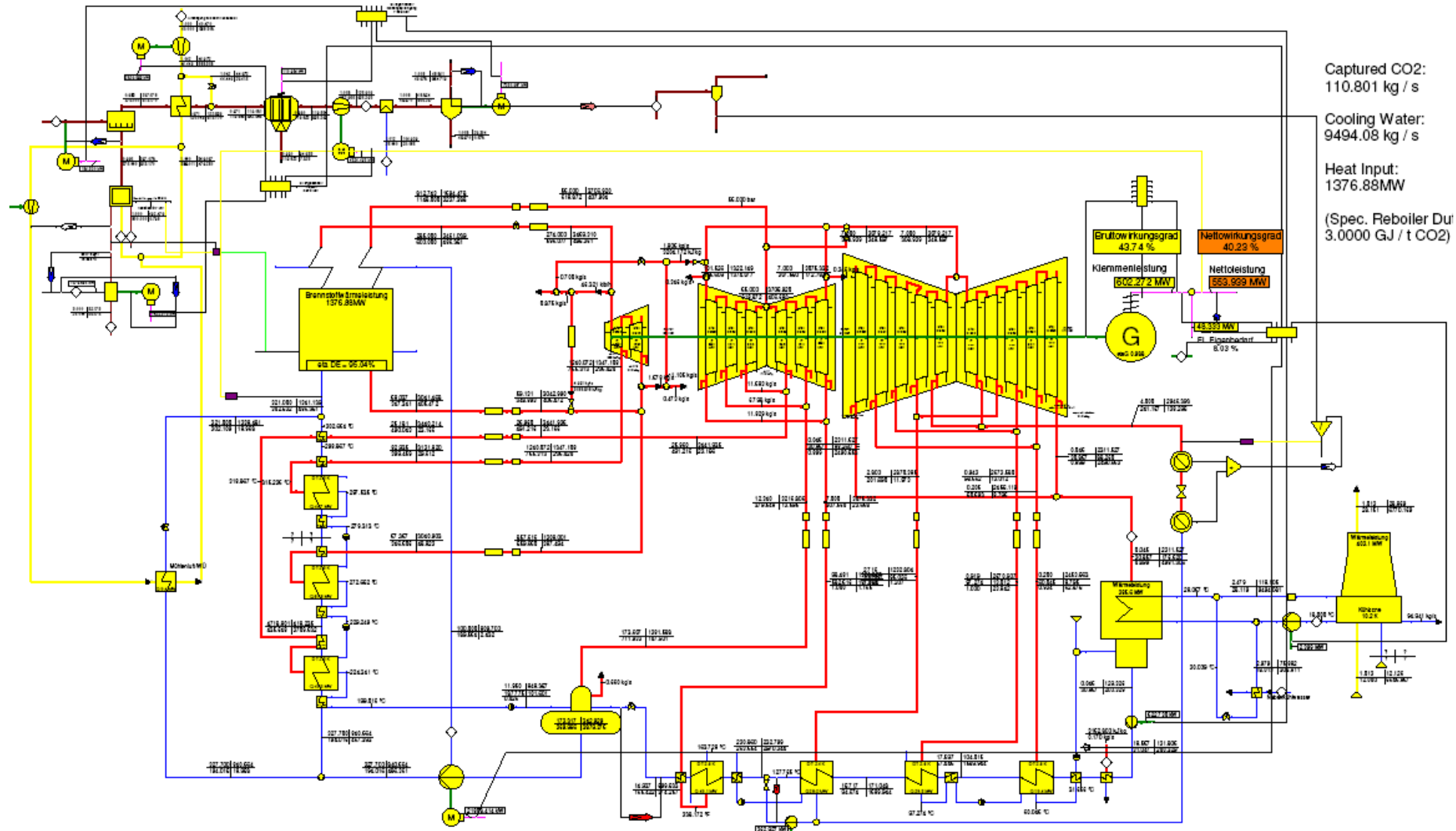
- Simulation tool: *ASPEN Plus*

- Technical data

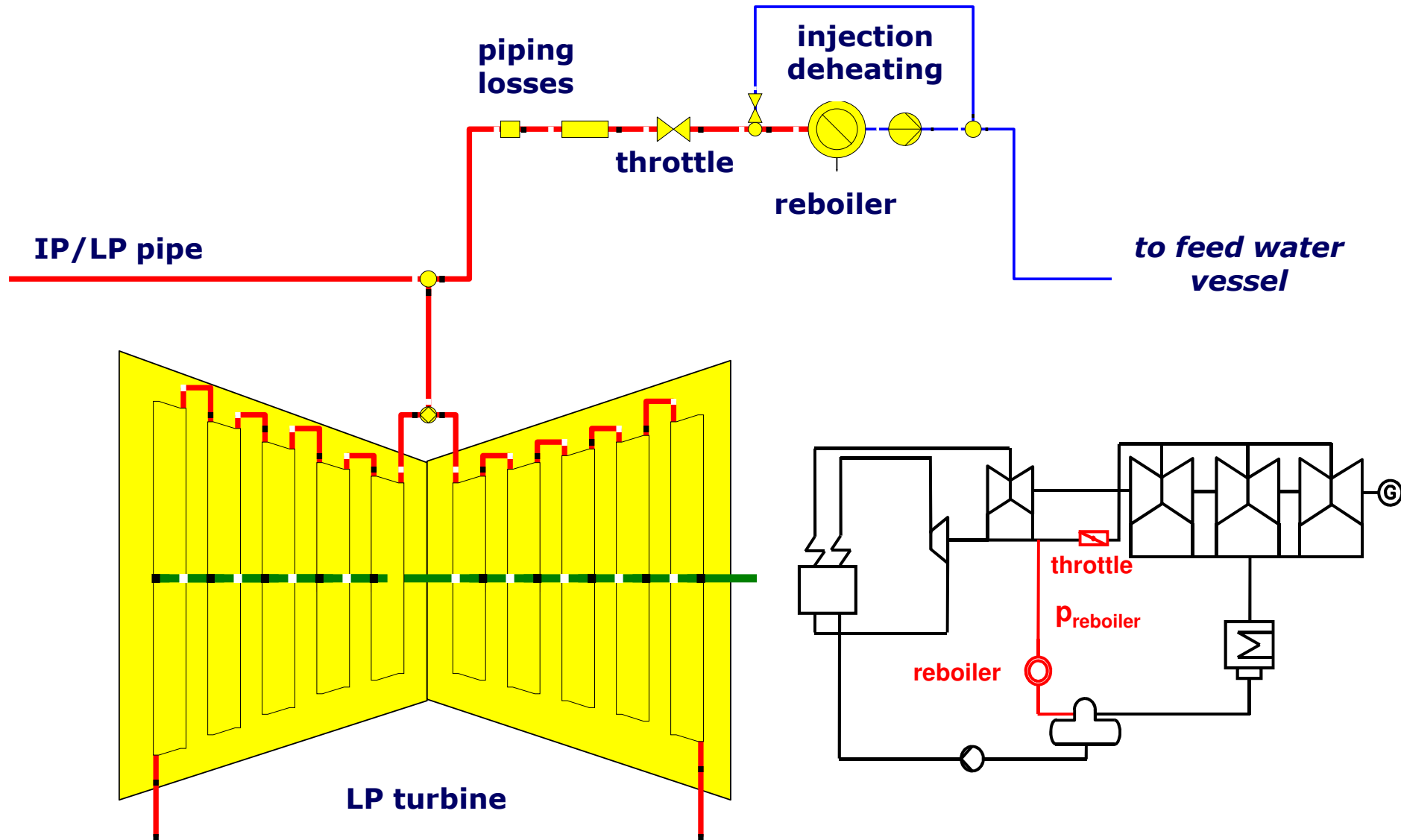
- ▶ 2 parallel trains of similar geartype compressors with **5 radial stages** ( $\eta_i = 0,84 \dots 0,87$ )
- ▶ 1 **booster** unit (outlet pressure 110 bar;  $\eta_i = 0,82$ )
- ▶ **electric drive**
- ▶ **intercooler** with water draw off after each stage ( $\Delta p_{\text{hot side}} = 100 \text{ mbar}$ )
- ▶ **aftercooler** (outlet temperature 40 °C)



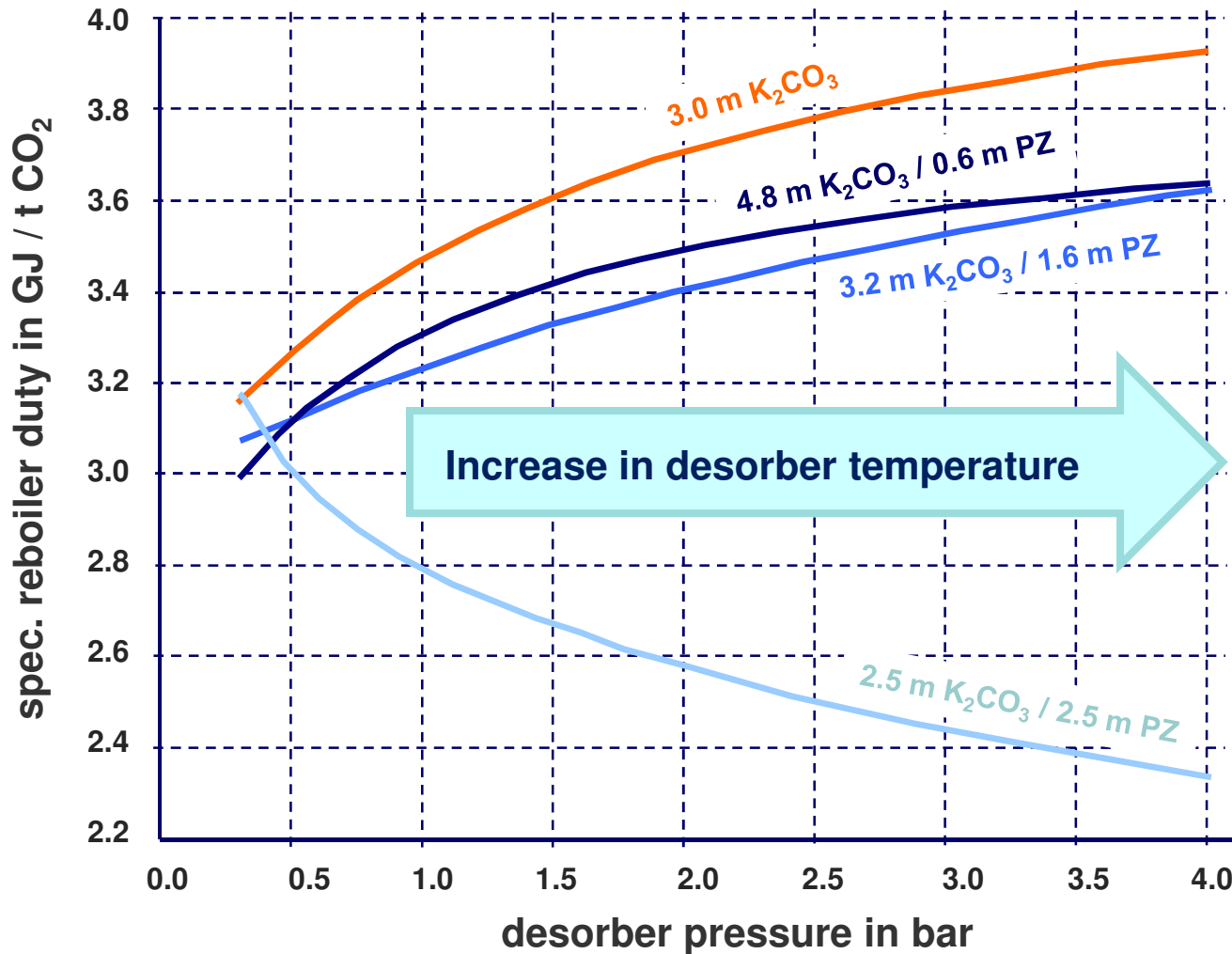
- 600 MW<sub>eI</sub> hard coal fired power plant in EBSILONProfessional:  $\eta_{\text{net}} = 45.6\%$  (LHV)



# Heat for Solvent Regeneration



# Effect of Desorber Pressure @ 90 % CO<sub>2</sub>-Capture Rate



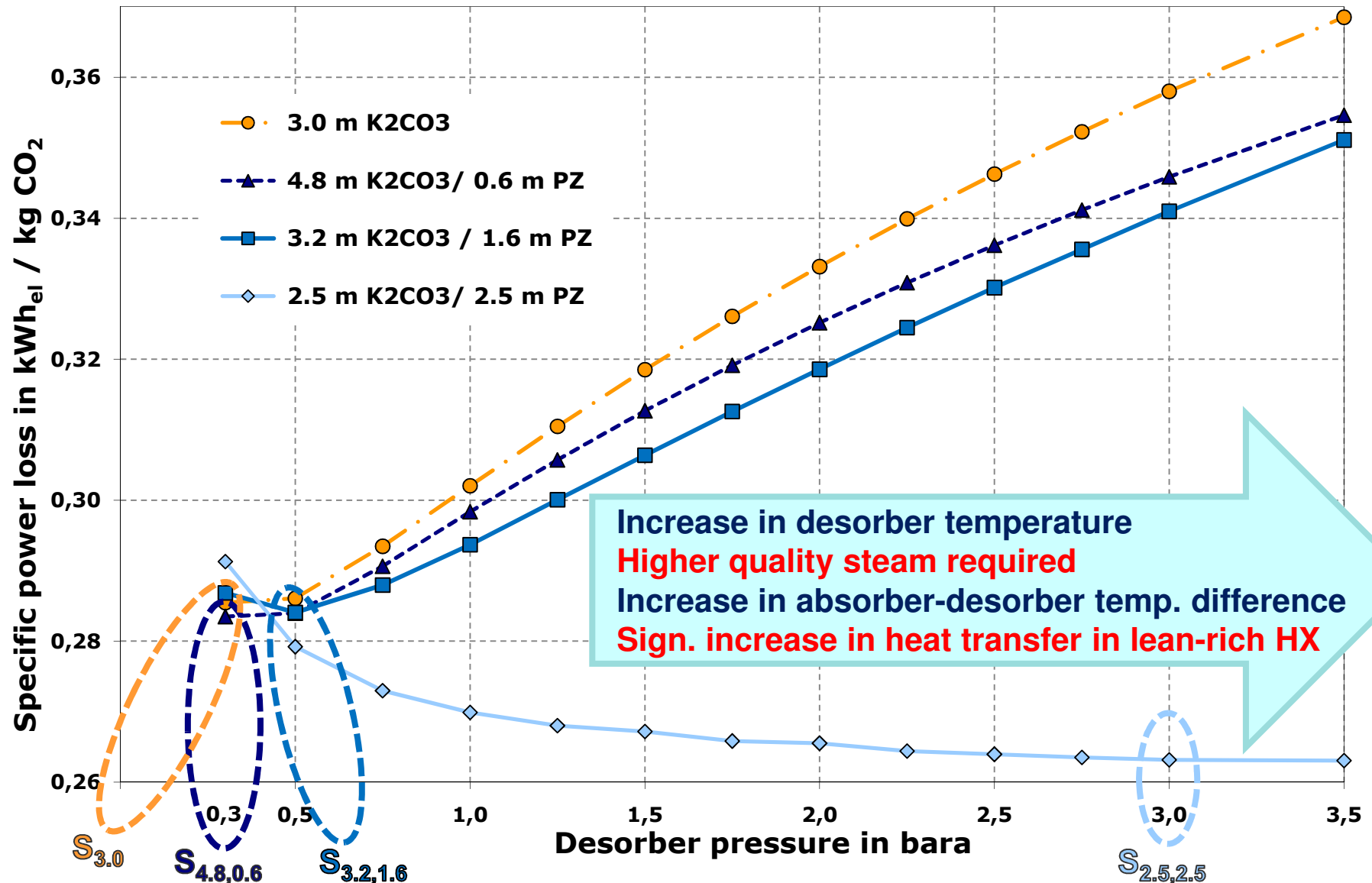
$$p_{\text{Desorber}} \uparrow \Rightarrow \left( \frac{p_{\text{H}_2\text{O}}}{p_{\text{CO}_2}} \right) \uparrow$$

$$\left( \frac{\Delta h_{\text{vap,H}_2\text{O}}}{\Delta h_{\text{abs,CO}_2}} \right) \downarrow$$

$$p_{\text{Desorber}} \uparrow \Rightarrow \left( \frac{p_{\text{H}_2\text{O}}}{p_{\text{CO}_2}} \right) \downarrow$$

**High heat of absorption solvents (*S*<sub>2.5,2.5</sub>) profit from temperature swing**

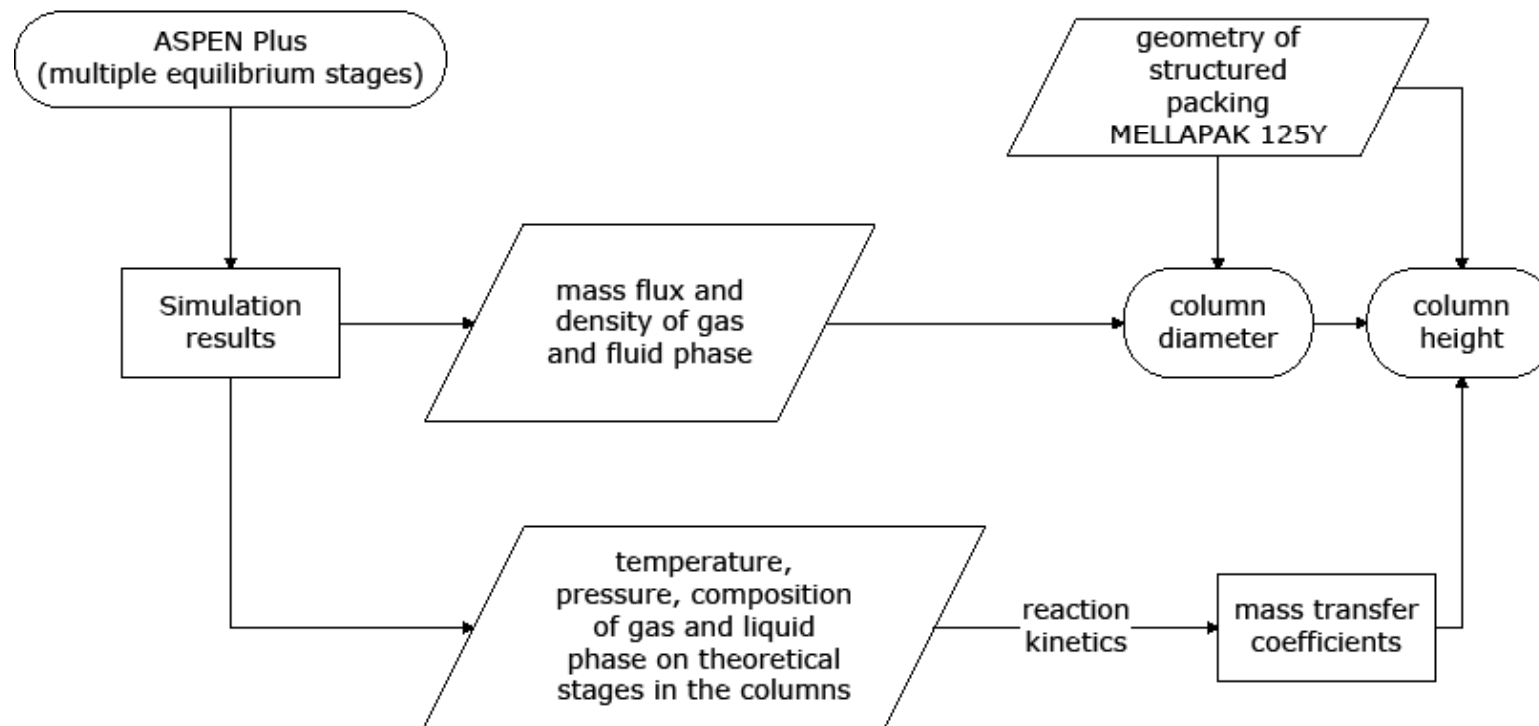
# Overall Energy Requirement @ 90 % CO<sub>2</sub>-Capture Rate

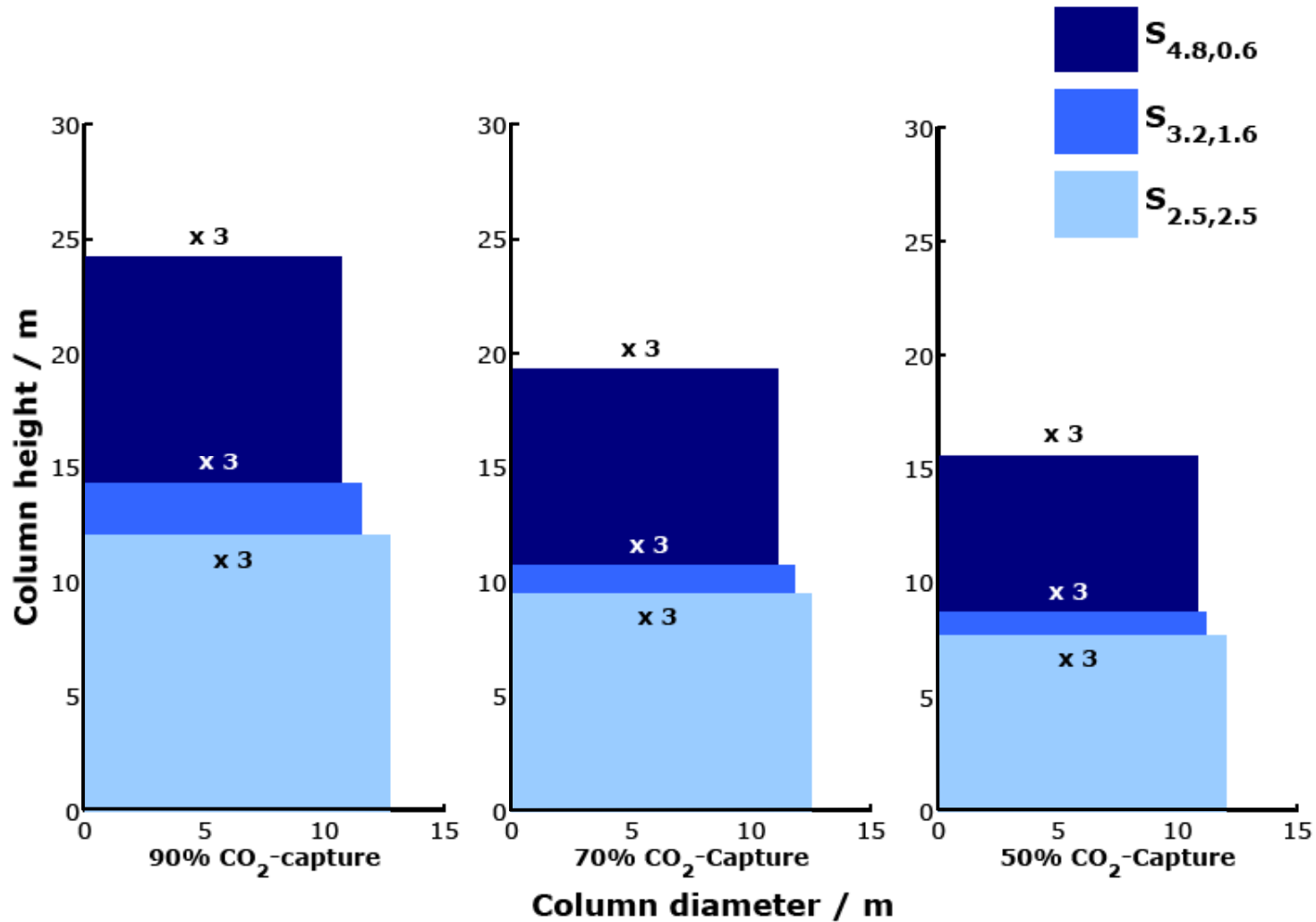


		S <sub>2.5,2.5</sub>	S <sub>3.2,1.6</sub>	S <sub>4.8,0.6</sub>	S <sub>3.0</sub>
CO <sub>2</sub> -capture rate	Desorber pressure (bara)	3.0	0.5	0.3	0.3
90 %	Spec. reboiler duty (GJ / t CO <sub>2</sub> )	2.44	3.12	3.00	3.16
70 %		2.07	2.68	2.57	2.92
50 %		2.05	2.65	2.52	2.92
90 %	Spec. power loss (kWh / t CO <sub>2</sub> )	263.2	341.0	345.9	358.0
70 %		243.5	300.1	307.7	334.6
50 %		252.5	304.1	312.3	343.3
90 %	Solvent circulation (kg / s)	9581	6705	4512	4350
70 %		9326	7491	5412	4596
50 %		7163	6169	4535	3442

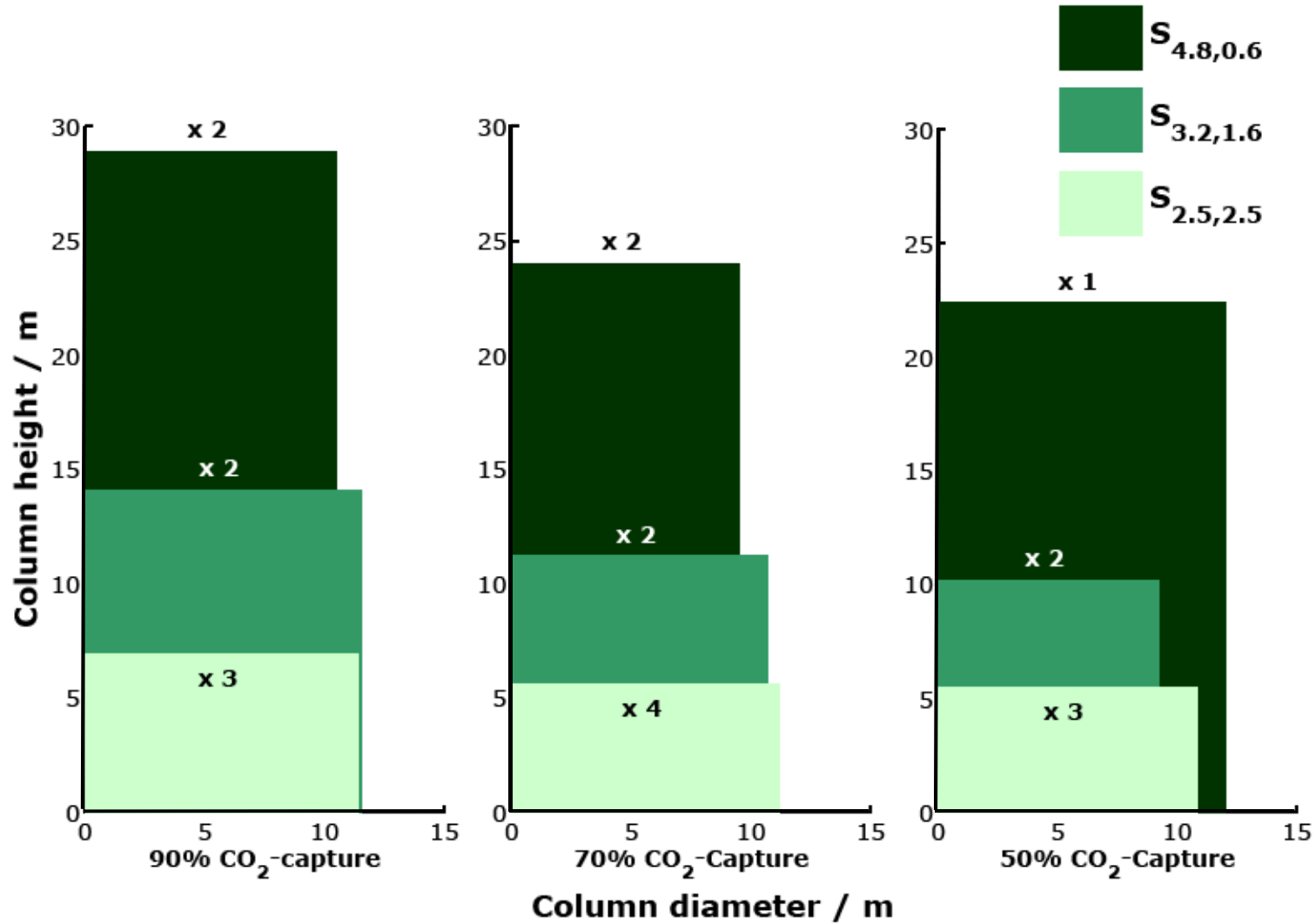
**S<sub>2.5,2.5</sub> shows lowest reboiler duty and power loss also for CO<sub>2</sub>-capture rates below 90 %**

- Multiple equilibrium stages in ASPEN Plus
- Results from simulation runs used to determine required packing diameter and height considering kinetic data by *Cullinane and Rochelle (2006)*
- Structured packing MELLAPAK 125Y, maximum column diameter 12.8 m





**Increasing height with lower PZ concentration due to reduced reaction kinetics.**

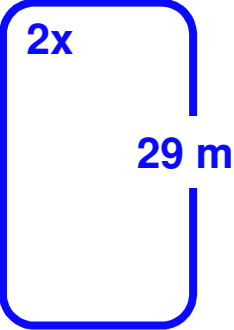





**More columns with higher PZ concentration due to larger solvent circulation rate.**

- Results from *Abu-Zahra et al. (2007)* for a MEA process are applied to the same power plant and CO<sub>2</sub>-compression model as used in this work
- Same methodology for process simulation, column sizing and cost estimation was applied in both works
- Comparison of energetic performance of integrated capture process, column sizes and specific column investment costs
- **Boundary conditions:**

	<u>MEA</u>	<u>2.5 m K<sub>2</sub>CO<sub>3</sub> / 2.5 m PZ</u>
▶ Solvent concentration (wt%)	30	22.1 / 13.8
▶ CO <sub>2</sub> -capture rate (%)	90	90
▶ Desorber pressure (bara)	2.1	3.0
▶ Reboiler temperature (°C)	128	125
▶ Lean loading (mol CO <sub>2</sub> <sup>tot</sup> / mol solvent)	0.32	1.01
▶ Pick-up range (mol CO <sub>2</sub> / mol solvent)	0.17	0.09
▶ Specific solvent flow (m <sup>3</sup> / t CO <sub>2</sub> )	27.8	74.4

# Comparison to MEA: Results

	<i>MEA (Abu-Zahra et al.)</i>		<i>K<sub>2</sub>CO<sub>3</sub>/PZ (this work)</i>	
spec. reboiler duty (GJ / t CO <sub>2</sub> )		3.3		2.4
spec. power loss (kWh / t CO <sub>2</sub> )		342		288
Δ net efficiency (%pts., LHV)		-11.3		-9.5
columns	<p>absorber</p>  <p>2x 29 m 11 m</p>	<p>desorber</p>  <p>1x 15 m 10 m</p>	<p>absorber</p>  <p>3x 12.0 m 12.7 m</p>	<p>desorber</p>  <p>2x 6.9 m 11.3 m</p>
absolute and spec. column invest. costs		10.9 M€ 352 € / (t CO <sub>2</sub> / h)		8.84 M€ 288.3 € / (t CO <sub>2</sub> / h)

- **Preliminary evaluation of  $K_2CO_3$ /PZ process was performed**
- **Influence of key parameters such as solvent composition, loading, desorber pressure and capture rate was analysed**
- **2.5 m  $K_2CO_3$  / 2.5 m PZ at 3 bara desorber pressure shows energetic advantageous over other solvent compositions**
- **Comparison of this solvent to a reference MEA-process from literature**
  - The application of  $K_2CO_3$ /PZ bares the potential of significantly reducing the heat required for solvent regeneration
  - Relatively low pick-up ranges at the optimal lean loading lead to large solvent circulation rates and thus to larger column diameters and/or number of required columns
  - Promotion with PZ and enhanced kinetics can lead to significantly smaller column heights
  - Even though larger column diameters or more columns are needed, overall investment costs turn out to be lower than in the MEA case

- **Re-simulation with new eNRTL parameter set by *Hilliard (2008)***
  - Fixed inaccuracies in calorimetry for H<sub>2</sub>O-K<sub>2</sub>CO<sub>3</sub>-PZ-CO<sub>2</sub>
  - Detailed parameter regression for H<sub>2</sub>O-MEA-CO<sub>2</sub>
- **Own calculations for MEA to compare K<sub>2</sub>CO<sub>3</sub>/PZ to MEA on a fair and unbiased basis**
- **Component pre-engineering design for all major components**
- **Detailed economic evaluation**
  - CAPEX, incl. investment costs for all major components, installation, engineering and construction
  - OPEX, e.g. for solvent make-up and maintenance
  - Determination of CO<sub>2</sub>-avoidance costs (€ / t CO<sub>2</sub>) and CoE (€ / kWh)

**Thank you for your attention!**

**Questions?**