The Oxyfuel Process with Circulating Fluidised Bed Combustion and Cryogenic Oxygen Supply

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Advantages of Circulating Fluidised Bed Boilers

- **Huge bandwidth of possible fuels**
- **Emission reduction by primary measures**
  - Low combustor temperatures and air staging reduce significantly the amount of NOx produced during combustion
  - SO_2-emissions can be reduced by in-situ desulphurisation
- **Oxyfuel → Next to the flue gas the circulated solids can be used as a heat sink for the process (in contrast to pulverised coal firing)**

→ Potential to reduce the amount of flue gas recirculated

Available Heat Sinks for Oxyfuel Processes

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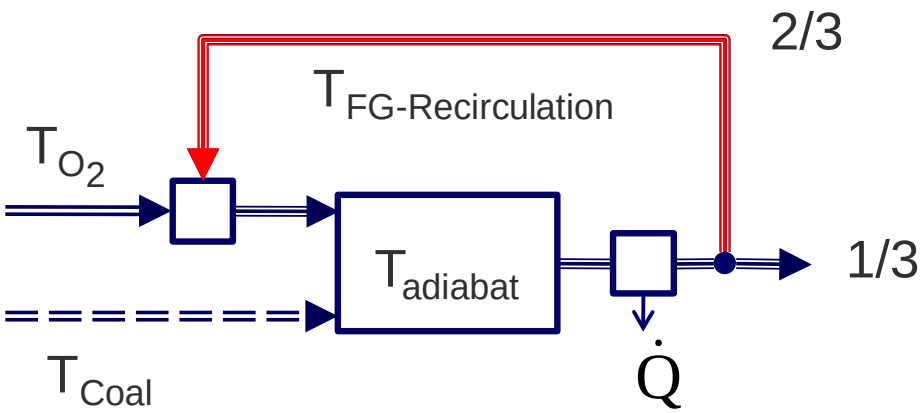
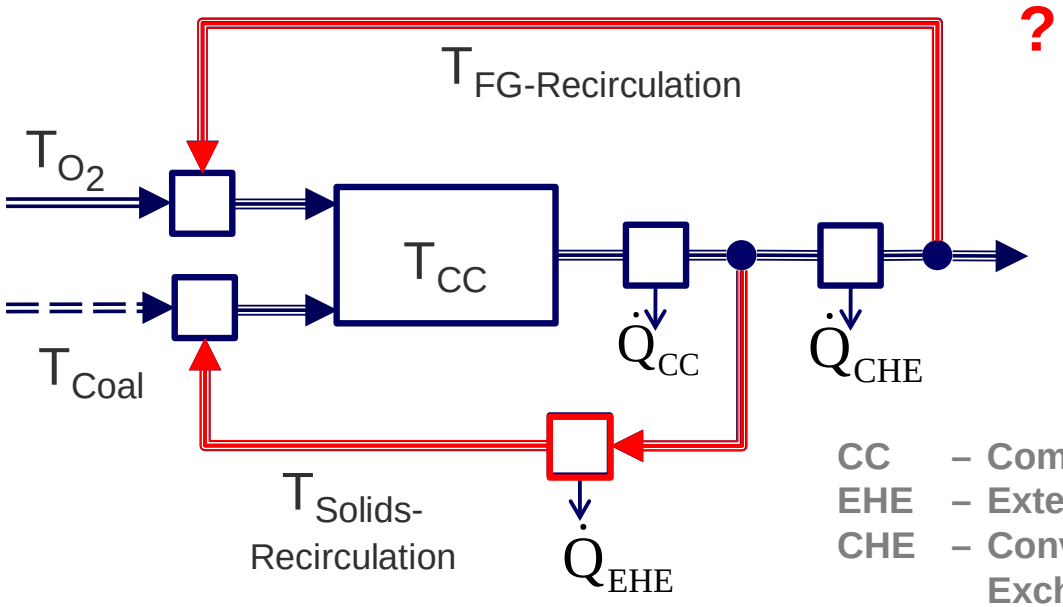
PC:



CFBC:



CC – Combustion Chamber
EHE – External Heat Exchanger
CHE – Convective Heat Exchanger

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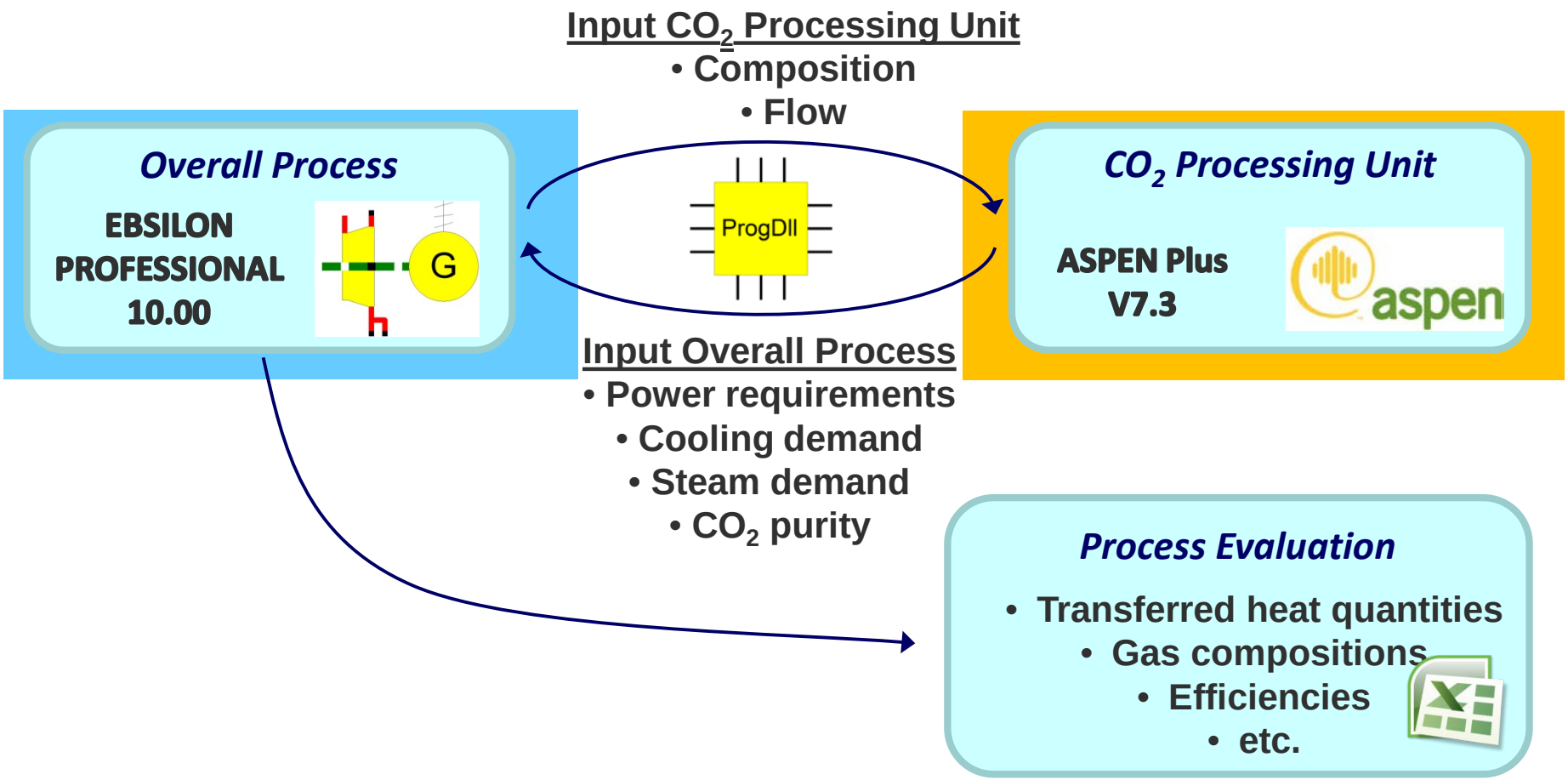
- **Link of EBSILON and ASPEN via ProgDLL allows the simultaneous execution of both software applications**



Process Scheme

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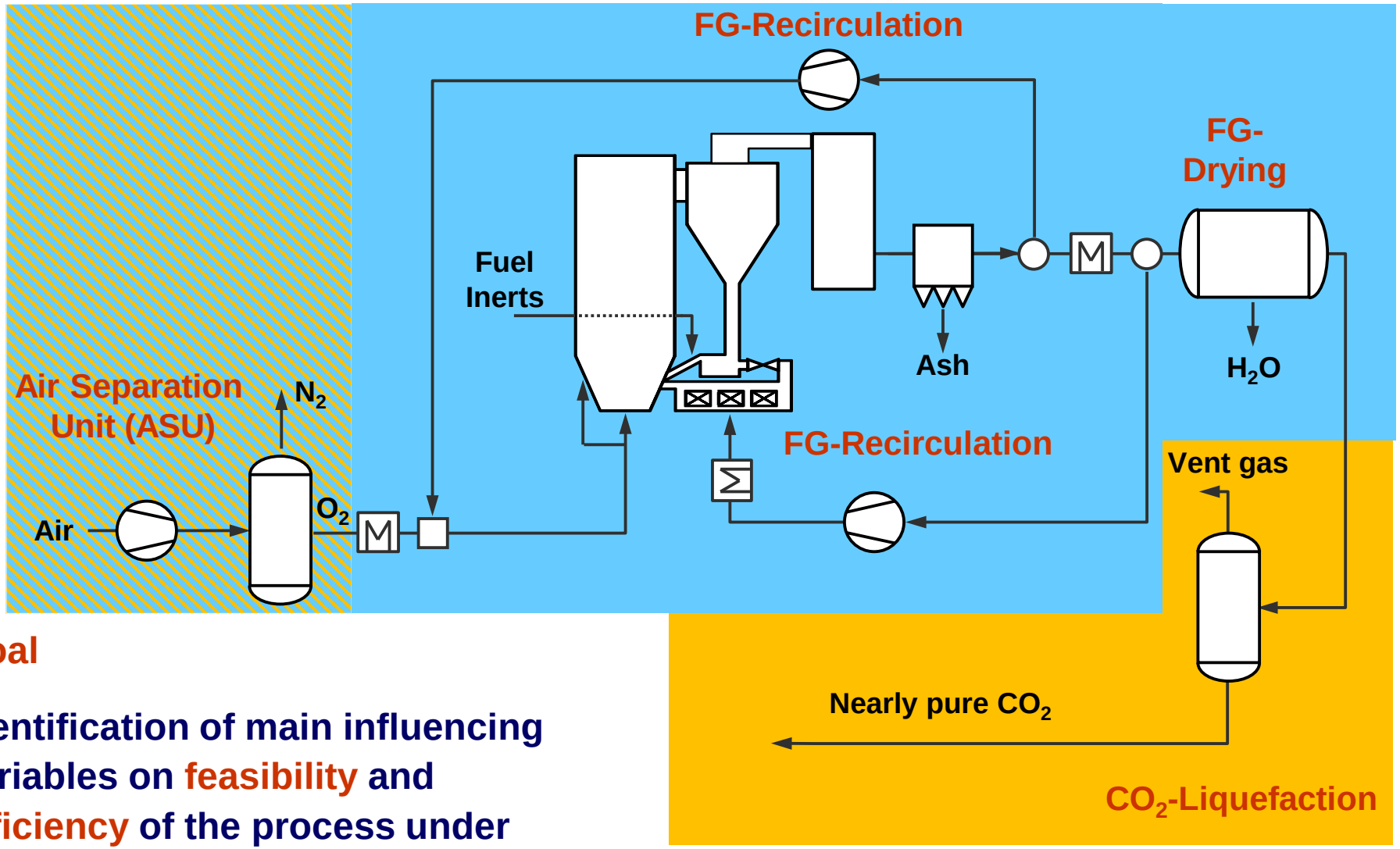

Goal

Identification of main influencing variables on feasibility and efficiency of the process under realistic boundary conditions

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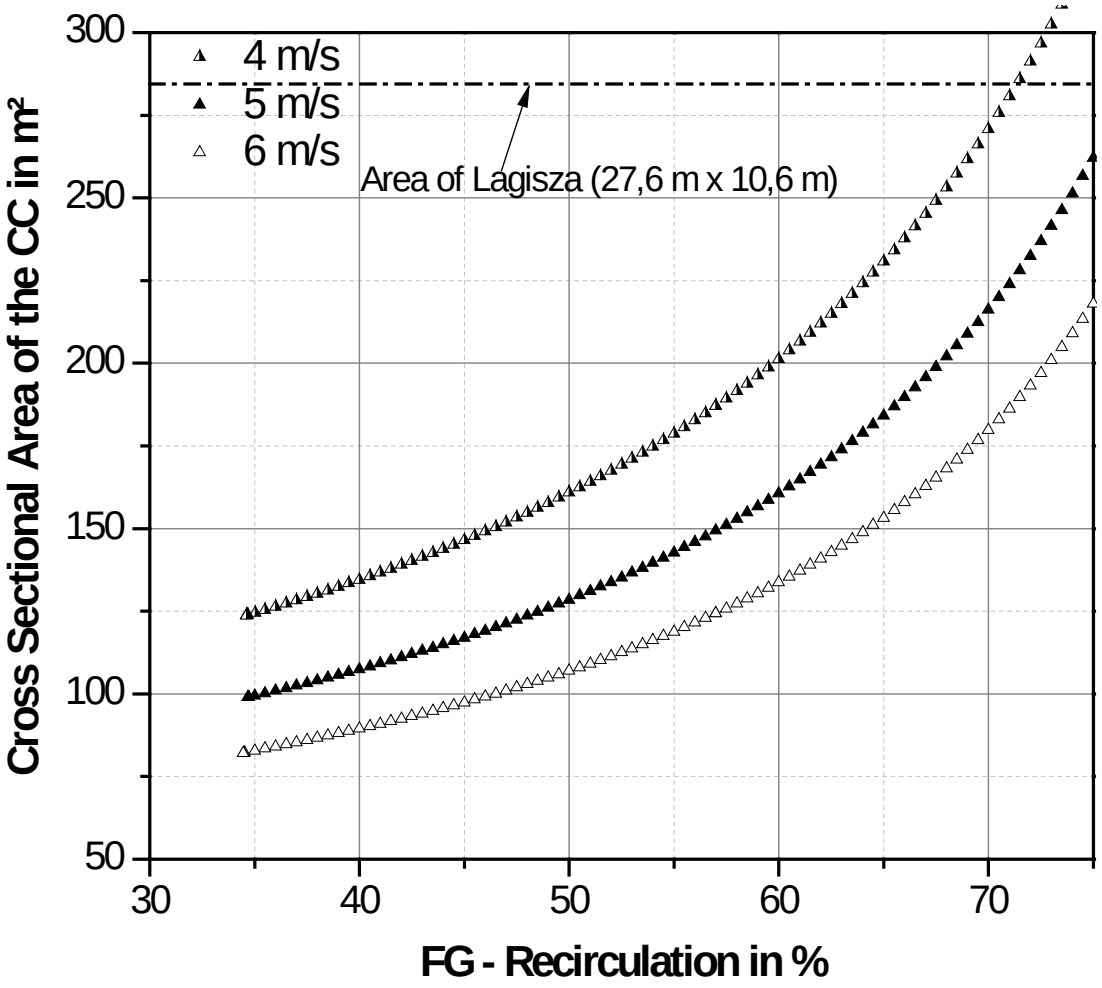
- **State-of-the-art power plant with EHE (460 $MW_{el,gross}$ – about 1000 MW_{th})**
- **South American hard coal (El Cerrejón – Burnout 99 %)**
- **CC-outlet: 880 ° C**
- **EHE-outlet: 550 ° C**
- **Steam parameters: 275 bar / 54 bar; 560 ° C / 580 ° C (SH/RH)**
- **Feed water temperature: 290 ° C ; FG outlet temperature (CHE) 340 ° C**
- **Temperature of recirculation (beneficial as hot as possible, limited by available fans)**
  - To CC: about 340 °C; To EHE: about 150 °C (preheated to 290 °C)
- **Oxygen ratio 1.15**
  - **Oxygen purity 95 volume-%**
  - **2 % air ingress at the convective heat exchangers**
  - **0.5 % air ingress at the electrostatic precipitator**

CC- Cross Sectional Area

- Reduction of the FG-Recirculation leads to a smaller cross sectional area of the CC and the CHE (u_0=const.)
- Same effect for higher velocities leading to:
  - Less available space for heat transferring areas → walls and additional equipment in the combustor (e.g. wing walls)
- Differences to Lagisza depend on simulated coal and u_0



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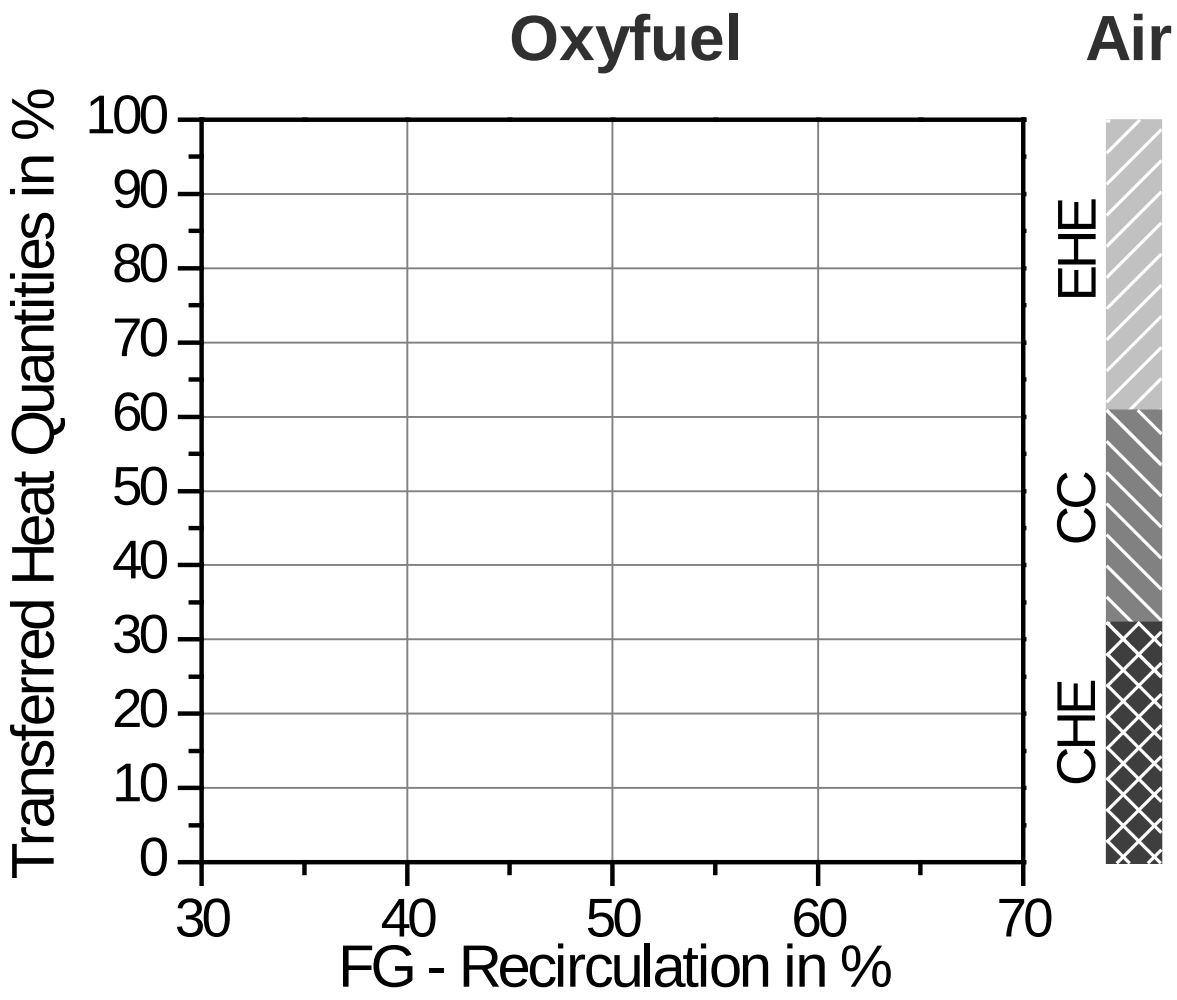
- About 32,5 % of the heat are transferred in the CHE
- Approximately 28,5 % are transferred in the CC (wing-walls with ribbed tubes and platen superheater)
- Remaining heat is transferred in the EHE (39 %)



Oxyfuel – Convective Heat Exchanger (CHE)

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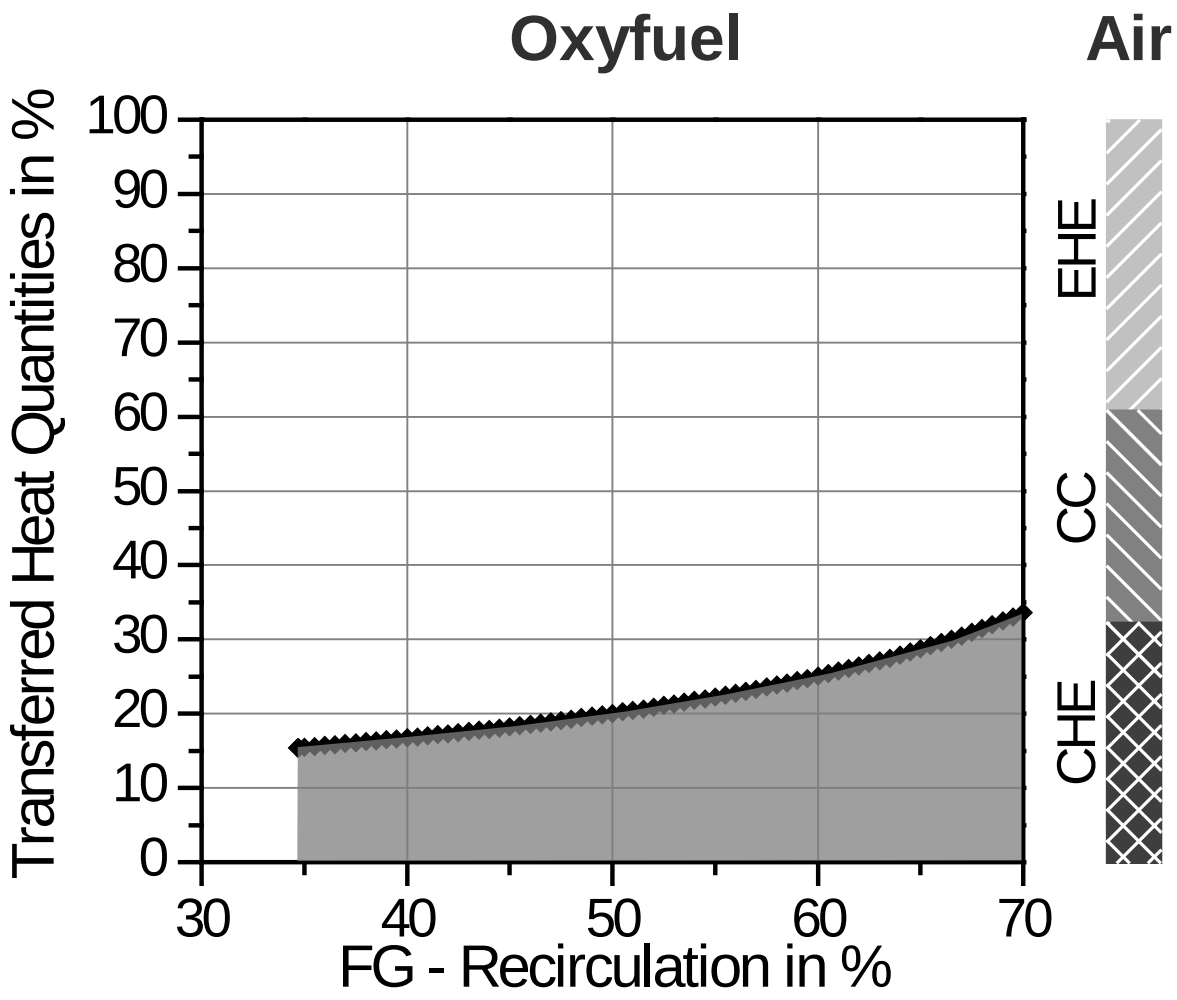
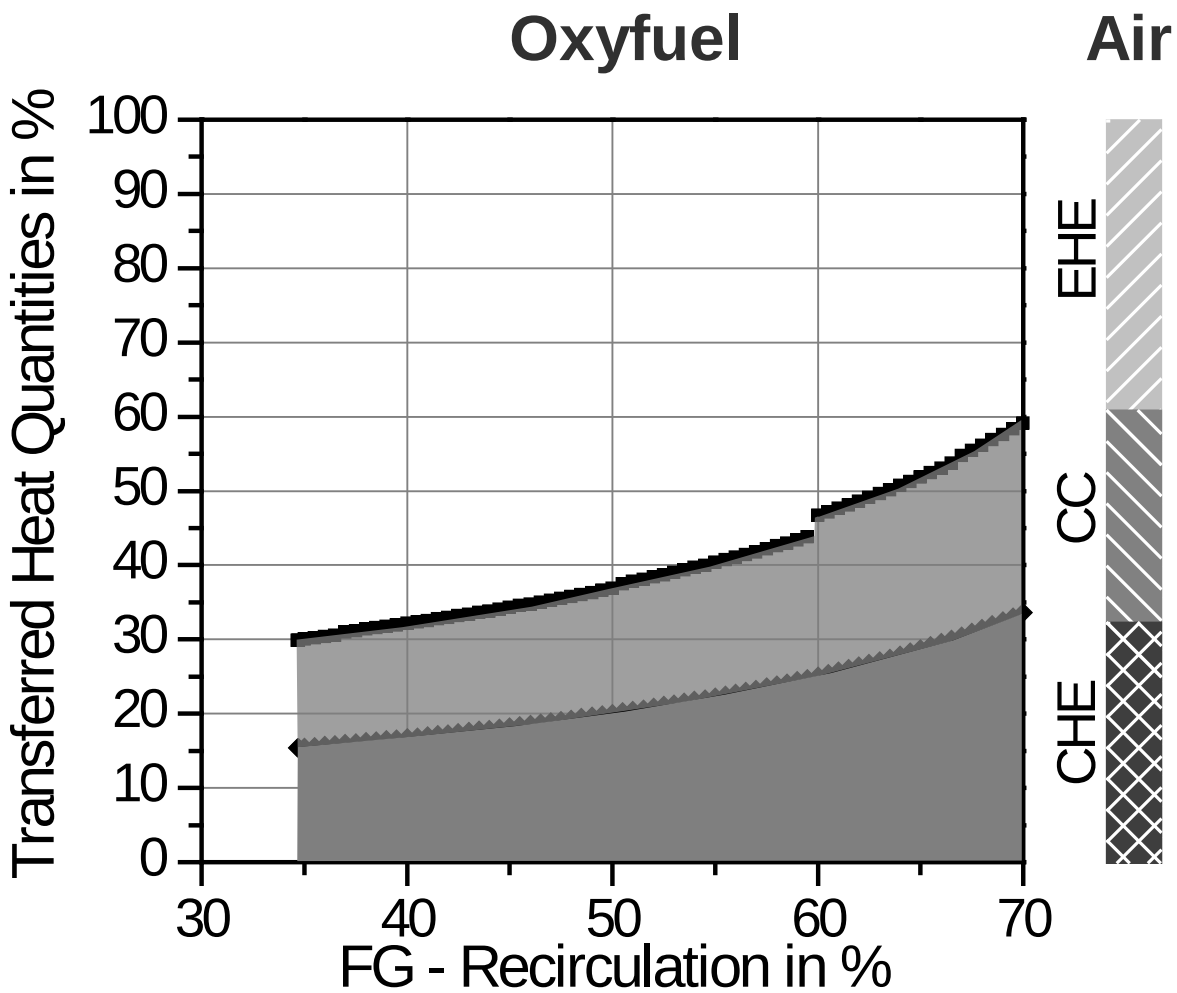
- Temperatures:
  $T_{CHE, in}$ = 880 °C,
  $T_{CHE, out}$ = 340 °C
- With a decreasing FG-recirculation there is less massflow through the CHE
  - Leading to less heat transferred in the CHE



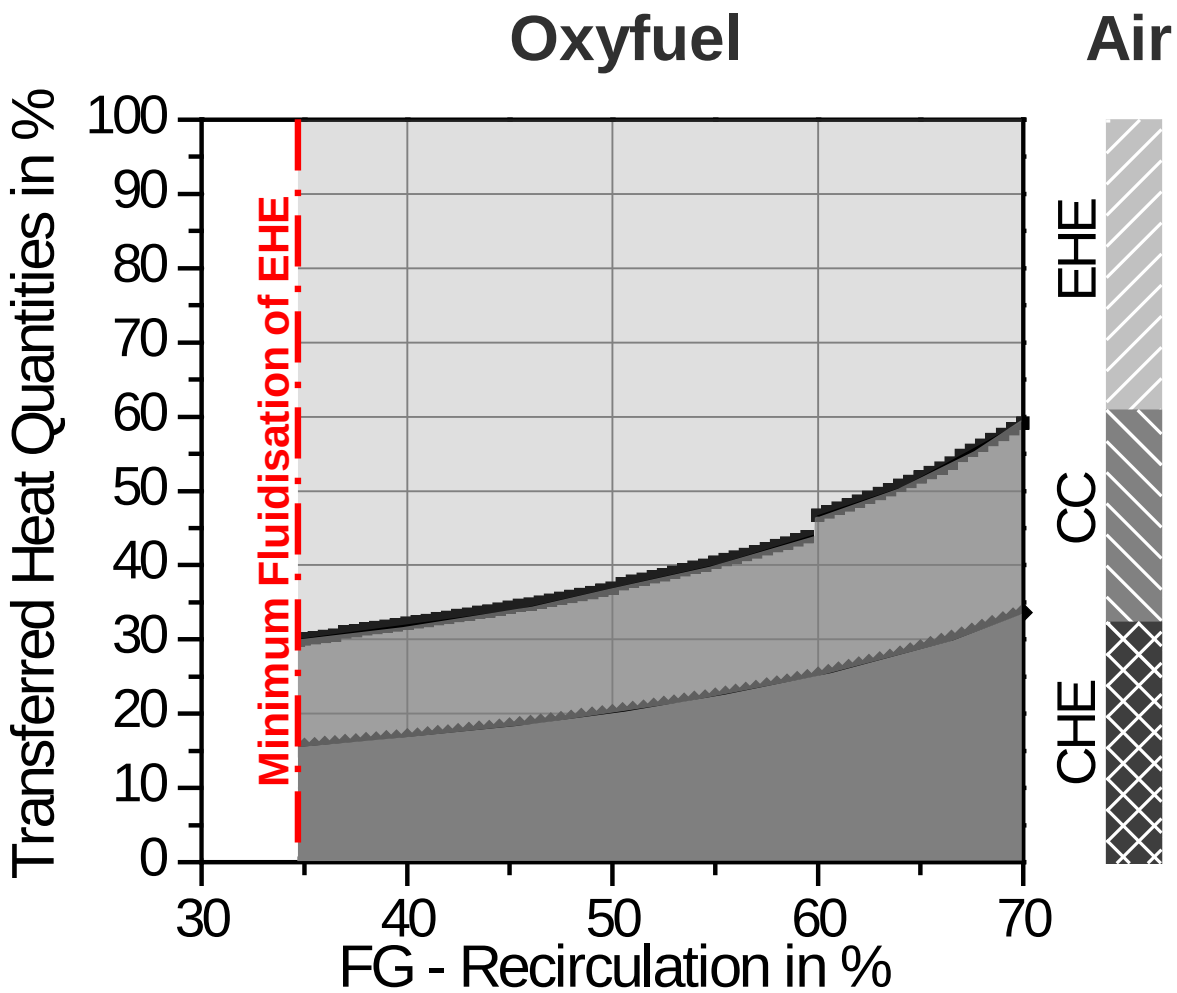
Oxyfuel – Combustion Chamber (CC) II

- A decrease in the FG-Recirculation leads to a smaller cross-sectional area (u_0=const.)
- Reduction of heat transferring area (wall and equipment)
  - Less heat can be withdrawn out of the CC
- More heat has to be transferred in the EHE



Oxyfuel – External Heat Exchanger (EHE) I

- The amount of heat transferred in the EHE increases with a reduction of the FG-Recirculation
- The theoretical minimum of FG-Recirculation is about **35 %**
  - The whole recycled FG is necessary to fluidise the EHE
  - CC O_2-Conc. in the CC nozzle floor exceeds limits → hot-spots in the bed



Oxyfuel – External Heat Exchanger (EHE) II

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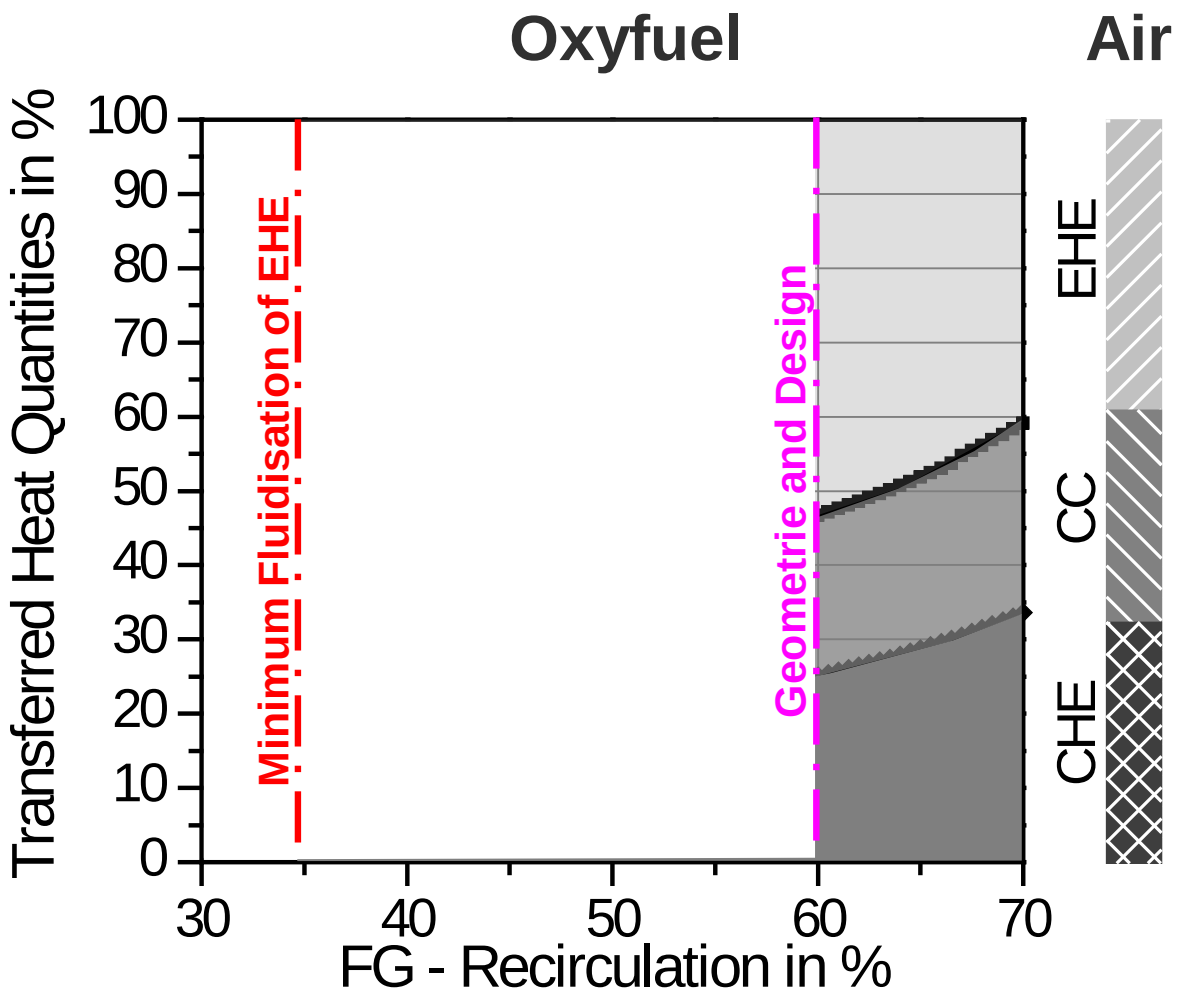
- The restricting limit for the range of operation of the Oxyfuel-CFB is the state-of-the-art of the EHE
  - Geometrical arrangement around the boiler is limited
  - Design of Loop-Seal and EHE
- Minimum for the FG-Recirculation > 60 %



Oxyfuel – External Heat Exchanger (EHE) III

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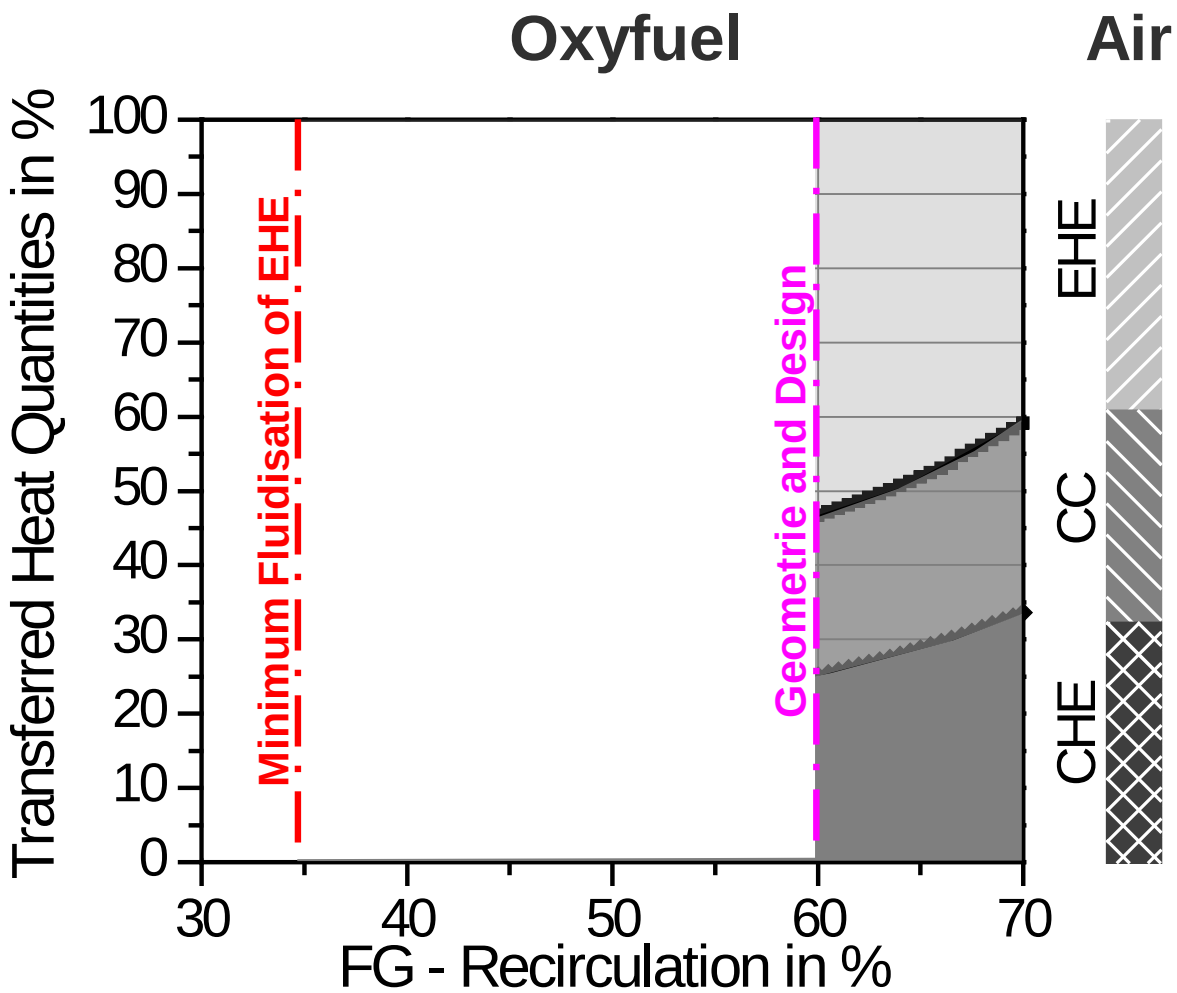
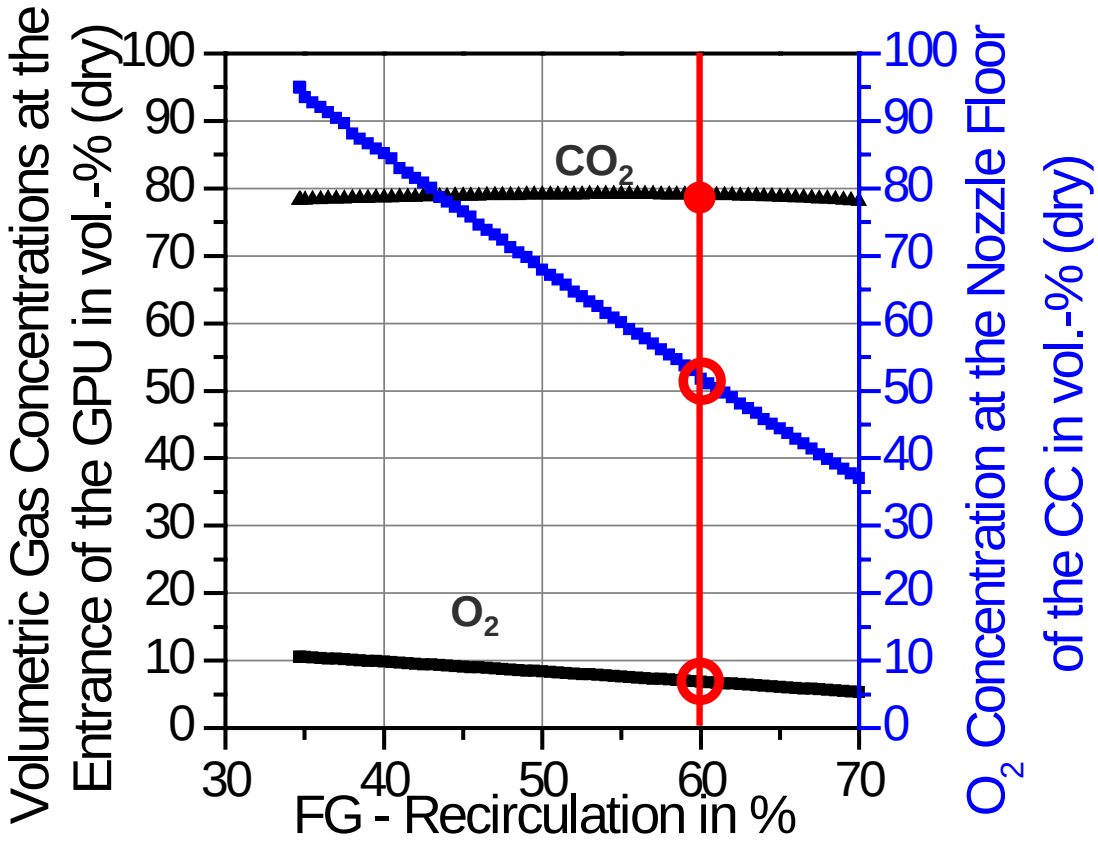
- Minimum for the FG-Recirculation ≈ 60 %
- Changes in the transferred heat due to Oxyfuel conditions:
  - CHE ≈ 25 % (- 7,5 %-pt.)
  - CC≈ 22 % (- 6,5 %-pt.)
  - EHE≈ 53 % (+14 %-pt.) **→ + 1/3**



Oxyfuel – Selected Flue Gas Concentrations

- Due to air ingress there is a maximum for the CO_2 concentration of 80 %
- For lower recycle rates the CO_2 concentration decreases due to an increase in residual oxygen
- The O_2 concentration in the flue gas increases accordingly
- The O_2 concentration at the CC nozzle floor increases for decreasing FG-Recirculation



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- **Assumptions**
  - Live steam parameter: 275 bar, 560 °C
  - Reheat: 54 bar, 580 °C
  - Condenser pressure: 45 mbar
  - ASU: 236 kWh/$t_{O2,pure}$ (adiabatic compression)
- **Calculated efficiencies for comparisons**

Air Case PC: $\eta_{el,net} \approx$ **44.2 %**

Air Case CFBC: $\eta_{el,net} \approx$ **43.3 %**

Δη = 0,9 %-pts.

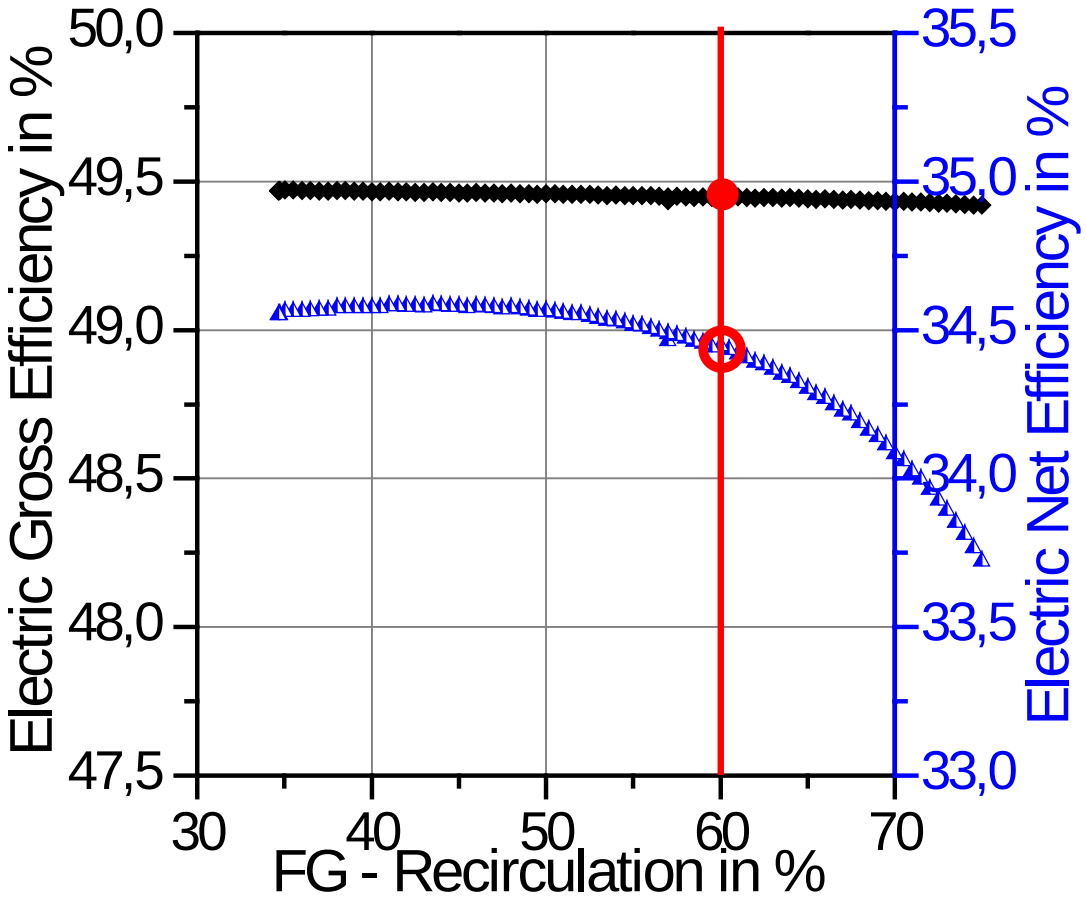
Oxy-PC: $\eta_{el,net} \approx$ **34,1-35,0 %**

Oxy-CFBC: $\eta_{el,net} \approx$ **34,1 % - 34,4 %**

Δη = 0 - 0,6 %-pts.

Oxyfuel – Efficiencies II

- For the chosen design the efficiency is at 34,4 % and by this comparable to PC-firing
- Slight demand increase for ASU and GPU
- The loss for higher recirculation is due to CC-Compressor
- The electrical demand for the EHE fan is dominated by the CC-compressor for higher FG-Recirculation



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- **The efficiencies of the CFBC are comparable to those of pulverised coal combustion, as long as no secondary flue gas treatment is necessary**
  - Efficiency loss in the order of 8 to 10 %-pts
- **Primary goal → Reduction of FG-Recirculation seems realisable, but is limited by:**
  - The fluidisation of the CC and EHE,
  - Arrangement of the boiler,
  - Design of Loop-Seal and EHE,
  - The solids entrainment

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Thank you for your attention!!

COORETEC-Cooperative Project: ADECOS ZWSF

„Oxyfuel-Process with Circulating Fluidised Bed Boiler“

Duration: 1st January 2010 - 31st March 2013

Institutes:

IET TU Hamburg Harburg
IFK Universität Stuttgart
VWS TU Dresden

Industry Partners:

EnBW Kraftwerke AG
E.ON Energie AG
RWE Power AG
Vattenfall Europe Generation AG & Co. KG
Linde AG
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