Techno-economic study of the CCMS technology for CO_2 capture from ferro-silicon production

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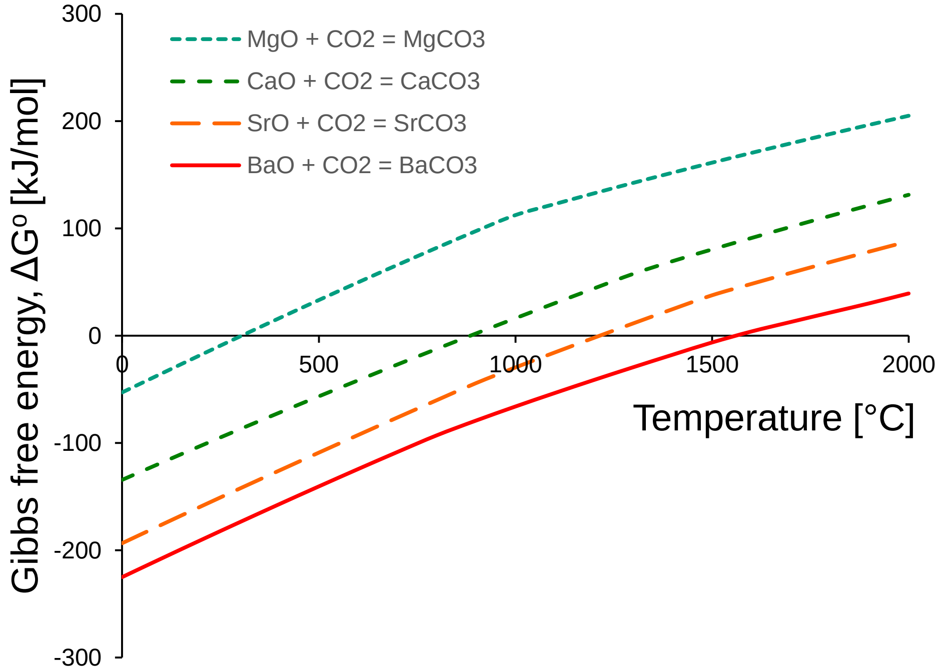
Carbon Capture in Molten Salts (CCMS)

- High temperature method for extracting CO_2 from a variety of flue gases related to power generation and **carbon-intensive industries**

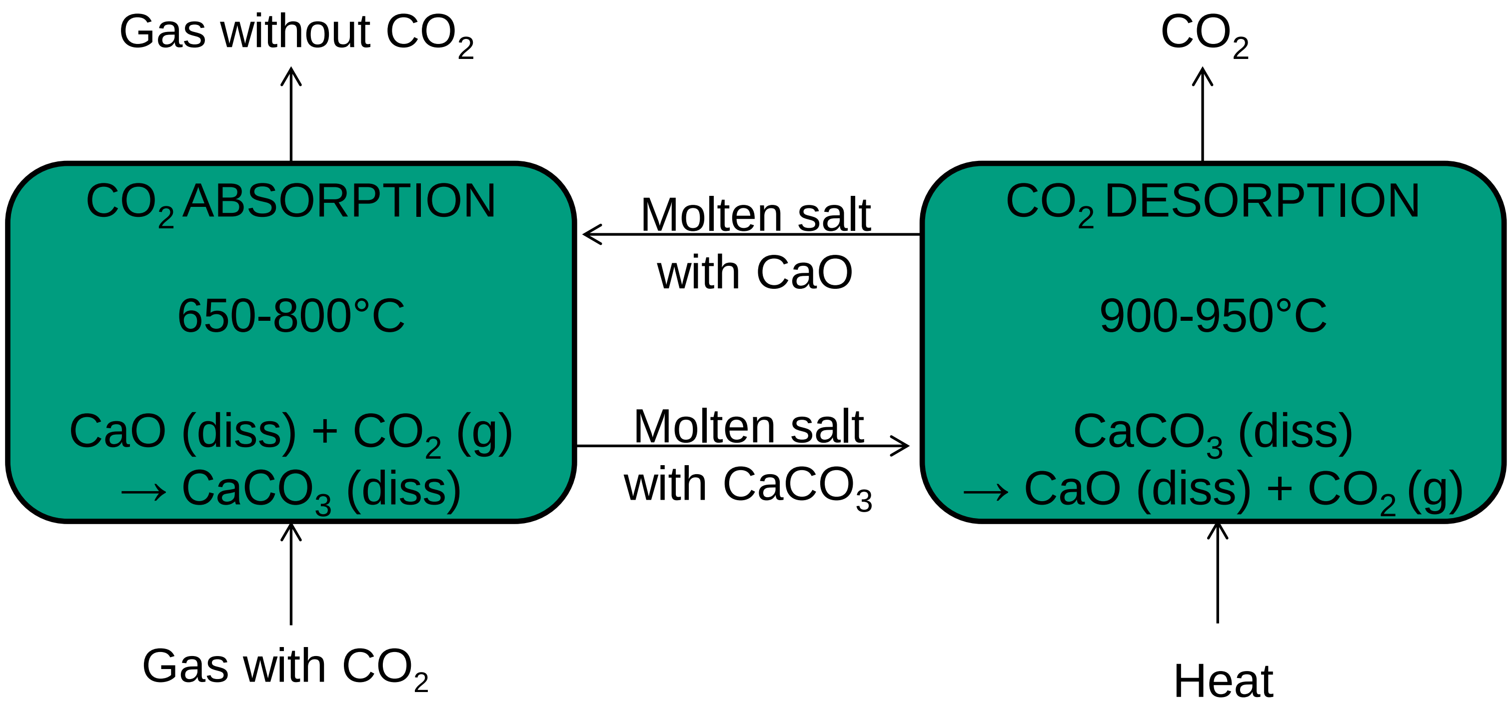
- Based on the reversible reaction between an alkaline earth metal oxide (e.g. CaO) and CO_2 to form a metal carbonate

$$MO\ (s) + CO_2\ (g) \leftrightarrow MCO_3\ (s)$$



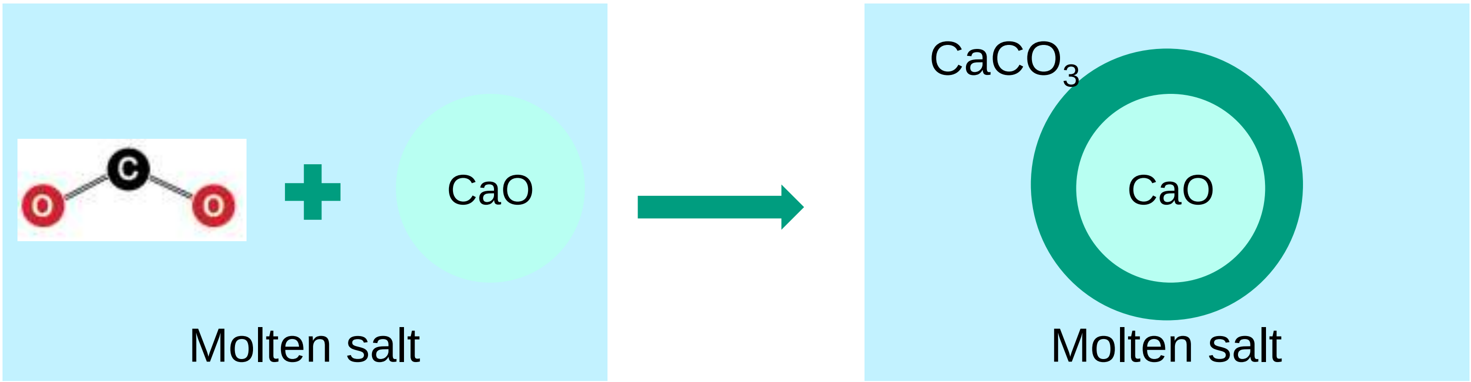
Carbon Capture in Molten Salts (CCMS)

- CCMS idea - molten salts are used as **chemical solvents** of the active substances



Carbon Capture in Molten Salts (CCMS)

- Hypothesis –formed $CaCO_3$ **dissolves** continuously in the melt



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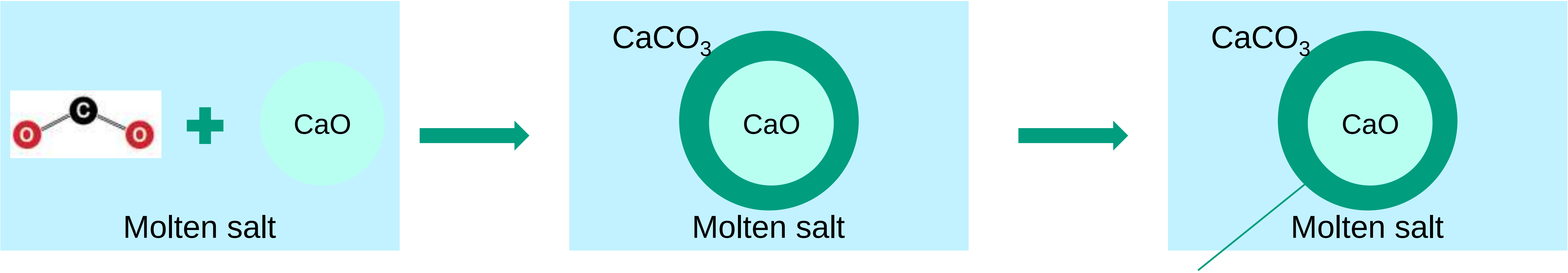


Highly **reactive CaO** readily available for the incoming CO_2

Carbon Capture in Molten Salts (CCMS)

- Laboratory scale experiments with CaO in chlorides / fluorides
  - One chamber reactor (< 1250°C)
  - Absorbing liquid ~ 100 g – 1 kg
  - Simulated flue gas (0 – 14 vol% CO_2 in N_2)
  - Gas analysis by FTIR
  - Thermogravimetric analysis

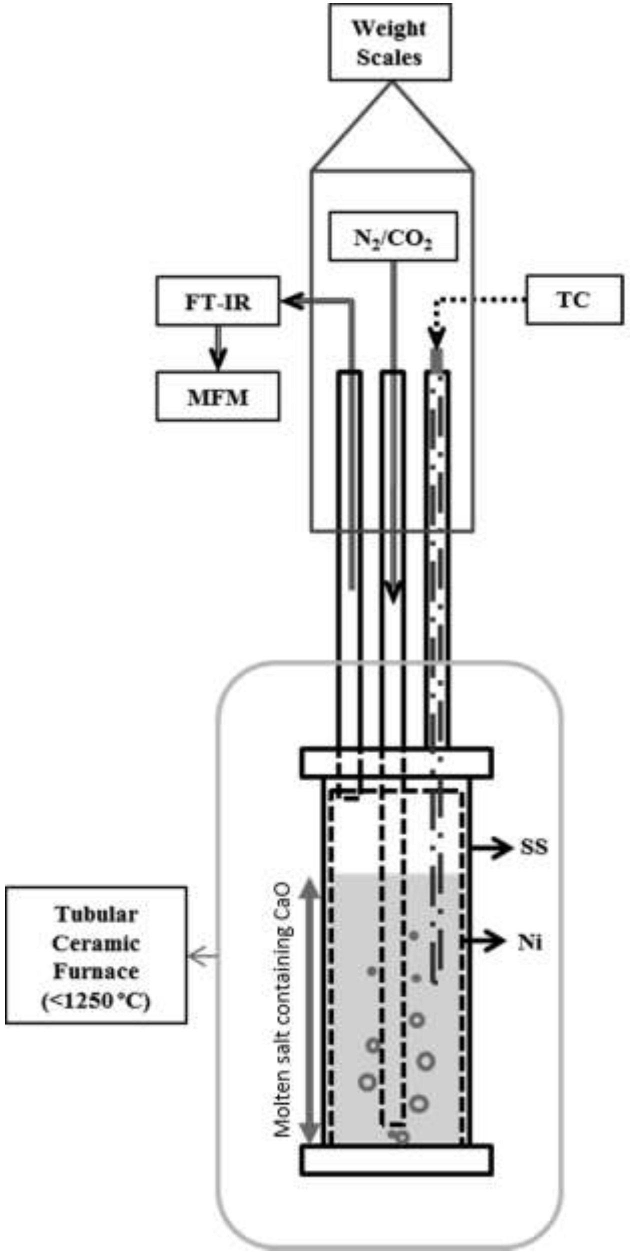
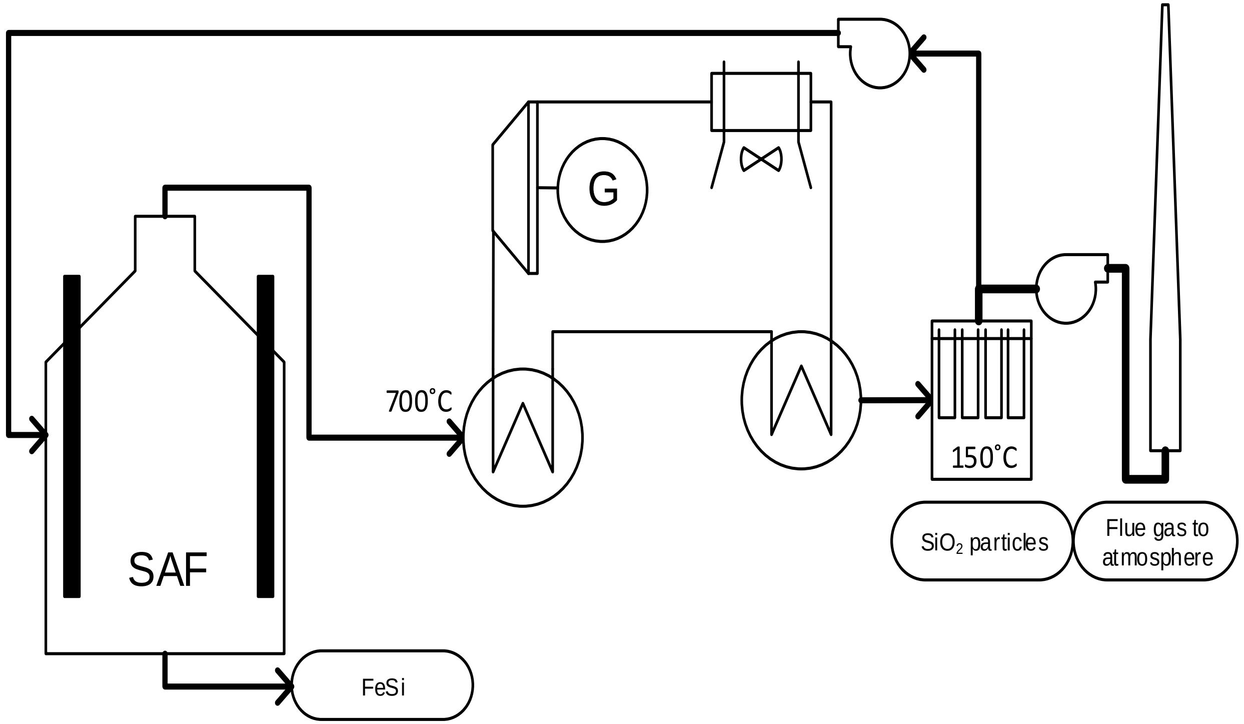


 Figure from: V. Tomkute, A. Solheim, E. Olsen, "Investigation of high temperature CO_2 capture by CaO in $CaCl_2$ molten salt", Energy and Fuels, 2013, 27, 5373-5379

Techno-economic study of the CCMS technology

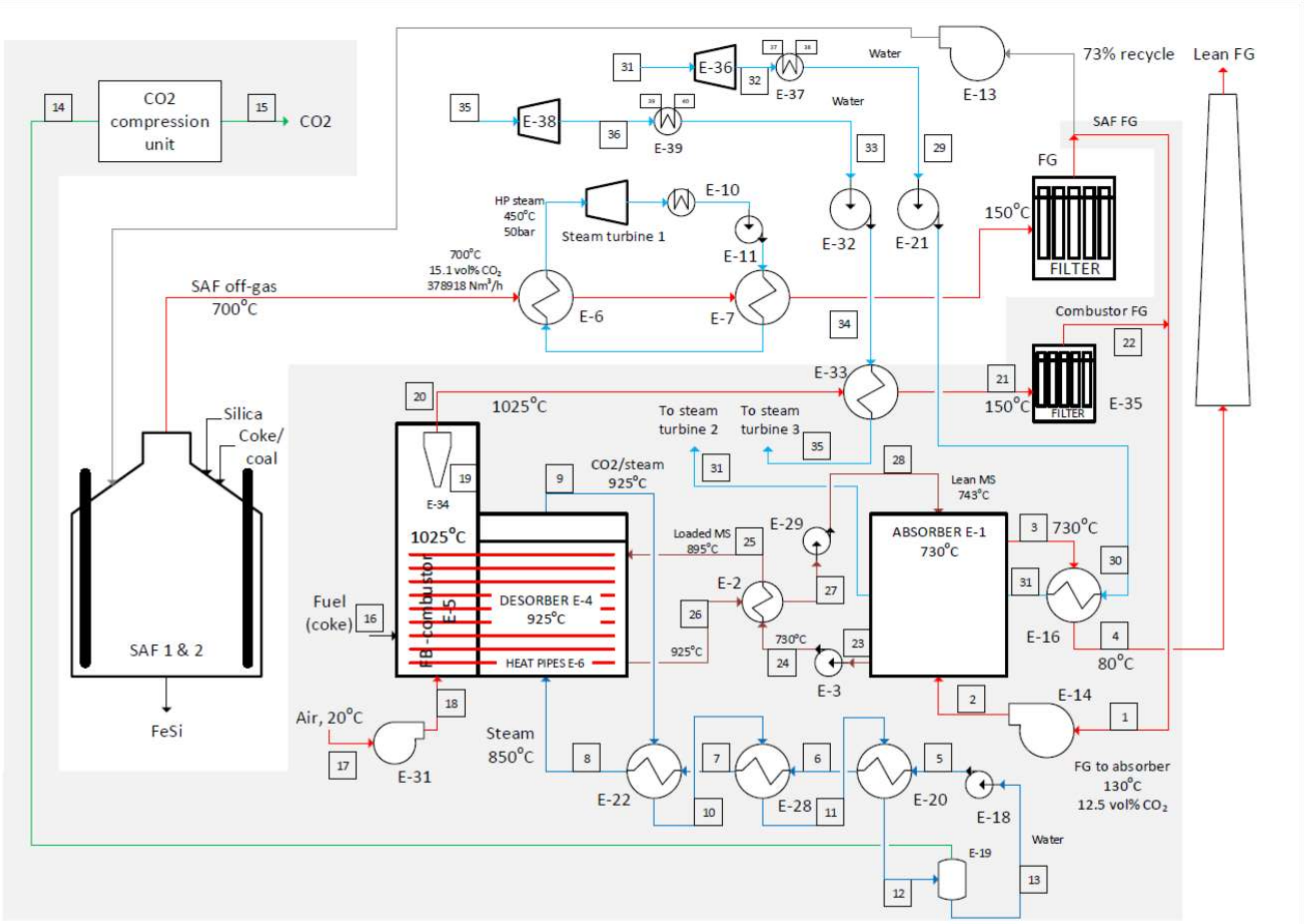
- Case study – 40 MW FeSi furnace with theoretical conciderations regarding recirculation of the flue gas



Characteristic	Value		
	No recycle	73% recycle	
	After filter	Before filter	After filter
Flow rate (Nm^3/h)	173 833	188 459	188 459
Pressure (mbarg)	-75	-45	-75
Temperature (°C)	130	150	130
Oxygen content (vol %)	16.4	6.00	6.00
Carbon dioxide content (vol %)	4.43	15.1	15.1
Water content (vol %)	4.28	11.8	11.8
Nitrogen content (vol %)	74.9	67.1	67.1

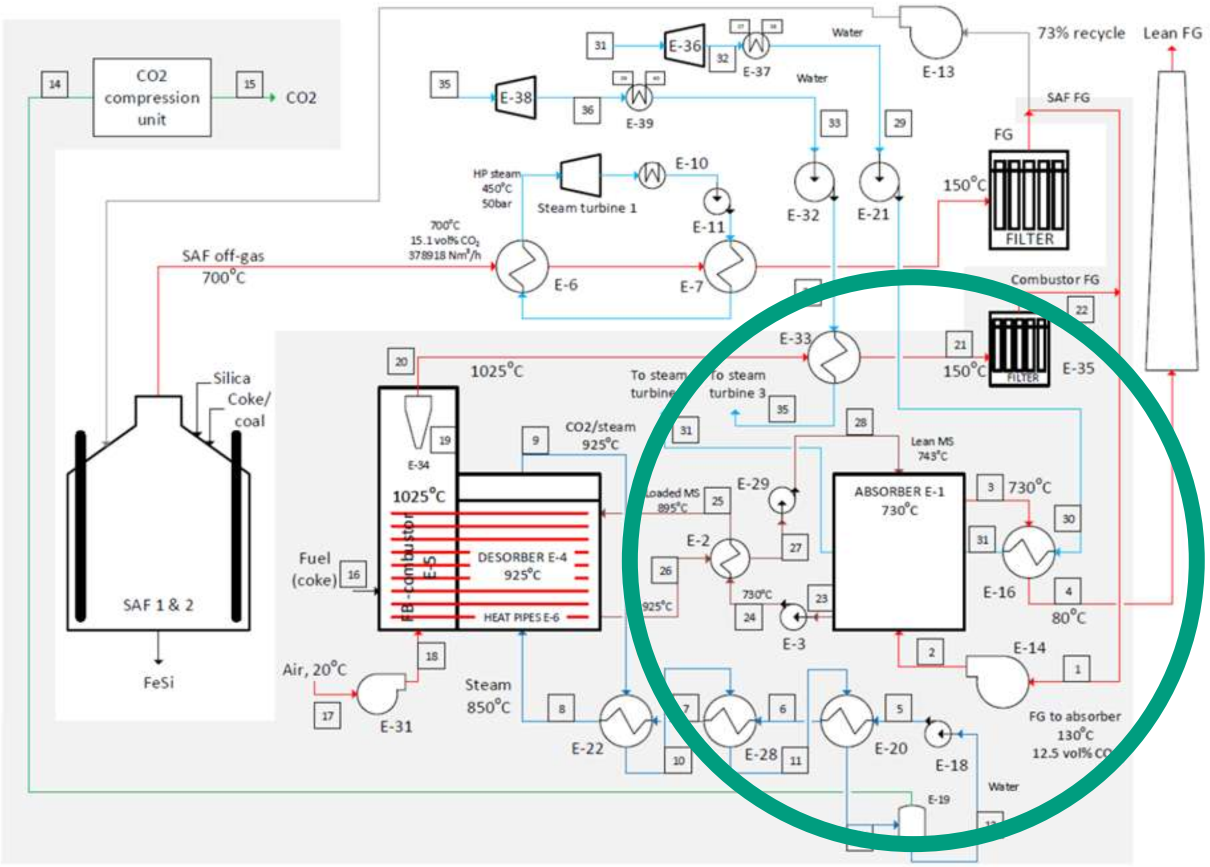
FeSi-furnace with CCMS (retrofitting)

- Grey area – scope of study



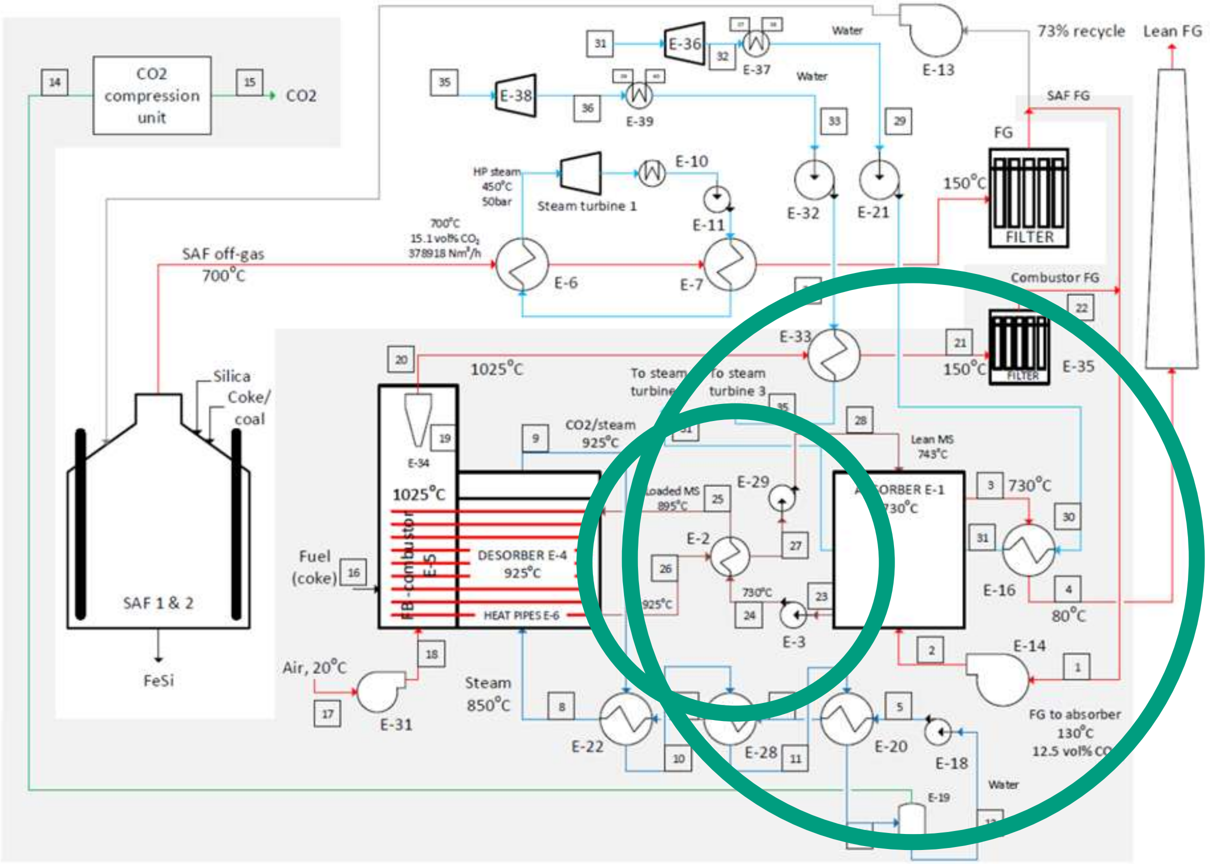
Absorber

- CO_2 content – 12.5 vol%
- Volumetric flow – 215 631 Nm^3/h (53 t/h CO_2)
- CO_2 capture rate – 85%
- Inlet temperature – 130°C
- Absorption temperature – 730°C
- Designed to be autothermal (exothermic reactions)



- Reaction kinetics based on experimental studies

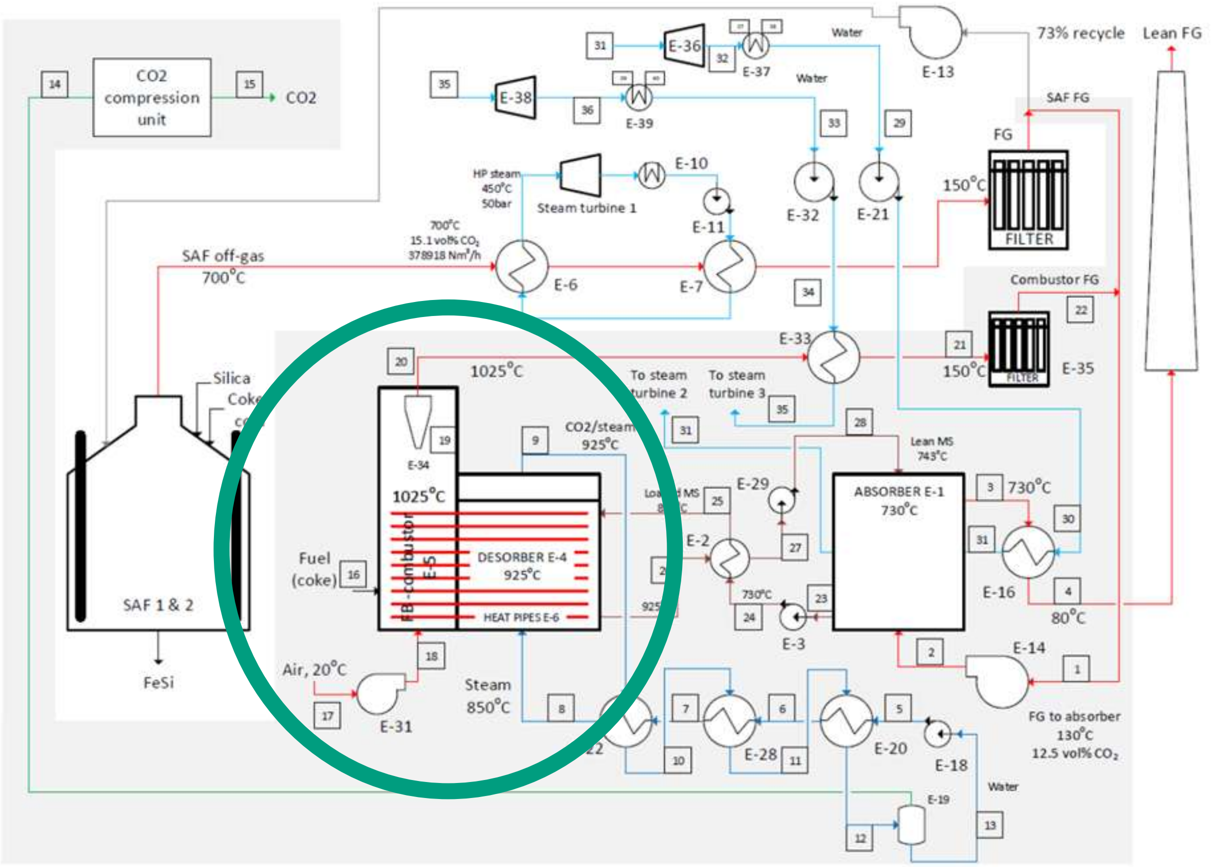
Absorber



- Absorber width and length – 12.1m (inner dimensions, square area)
- Total reactor height – 14.4m (reaction zone height of 9.1m)
- Gas contact time – 6s
- Loaded and lean molten salts are transferred by pumps between the absorber and desorber

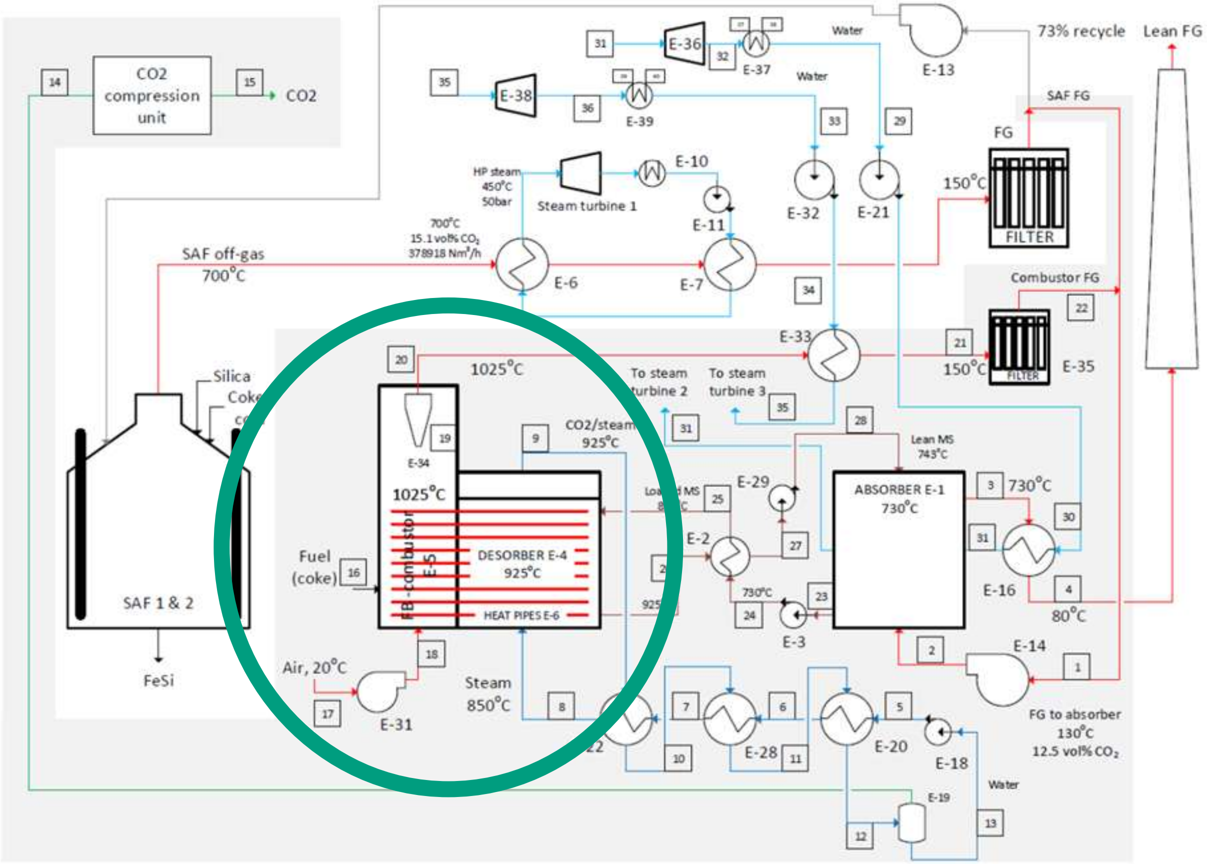
Desorber

- Desorber requires heat supply in order to regenerate the molten salt mixture at 925°C
- Proposed system – fluidized bed combustor (1025°C) and heat pipes (in red) with sodium as working medium



- Total of 154 tubes are needed (outer diameter 0.168m and length 23.8m)
  - 7 rows with 22 horizontal tubes per row
  - Sodium mass flow – 12.2 kg/s

Desorber



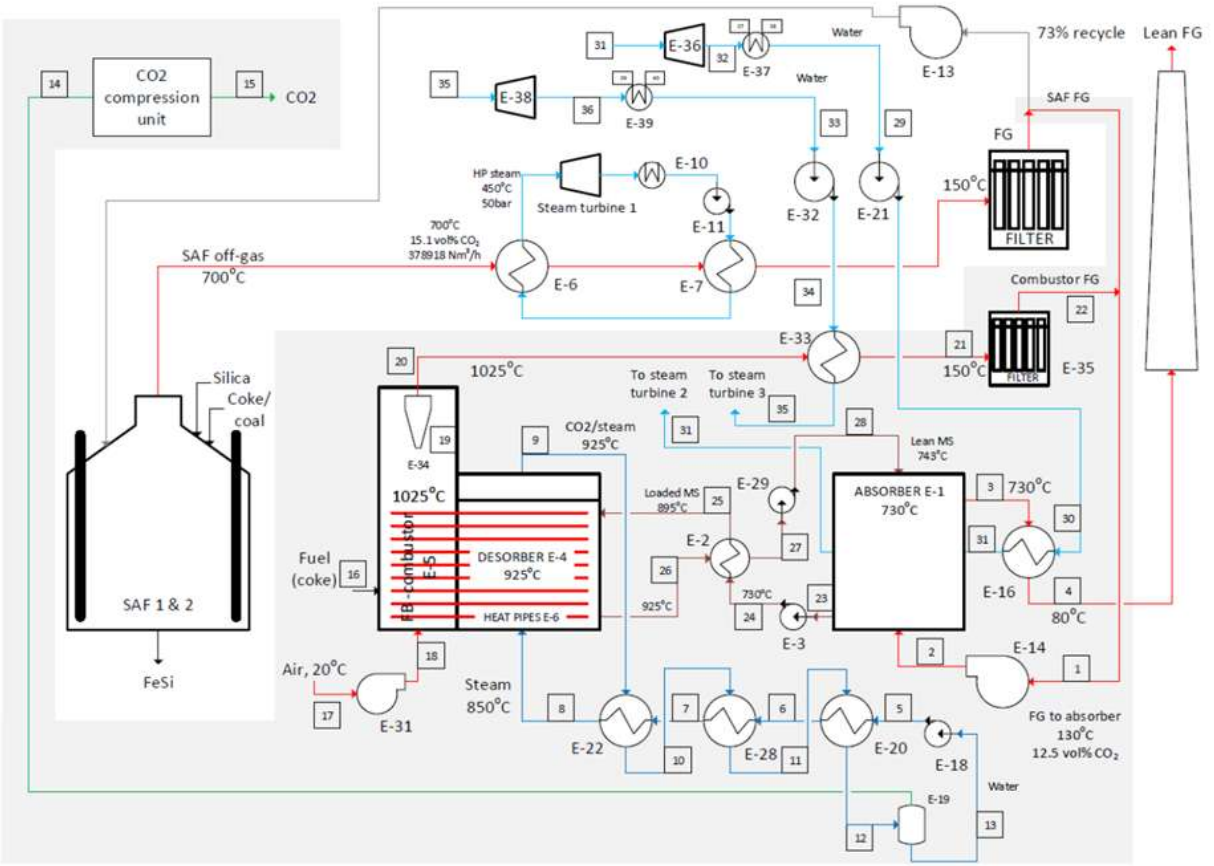
- Desorber
  - Width – 13.1m, length – 14.5m
  - Height – 10.5m

- Combustor
  - Width – 11.3m, Length – 14.5m
  - Temperature – 1025°C

- Resulting total ground area for combustor and desorber system is 353 m^2.

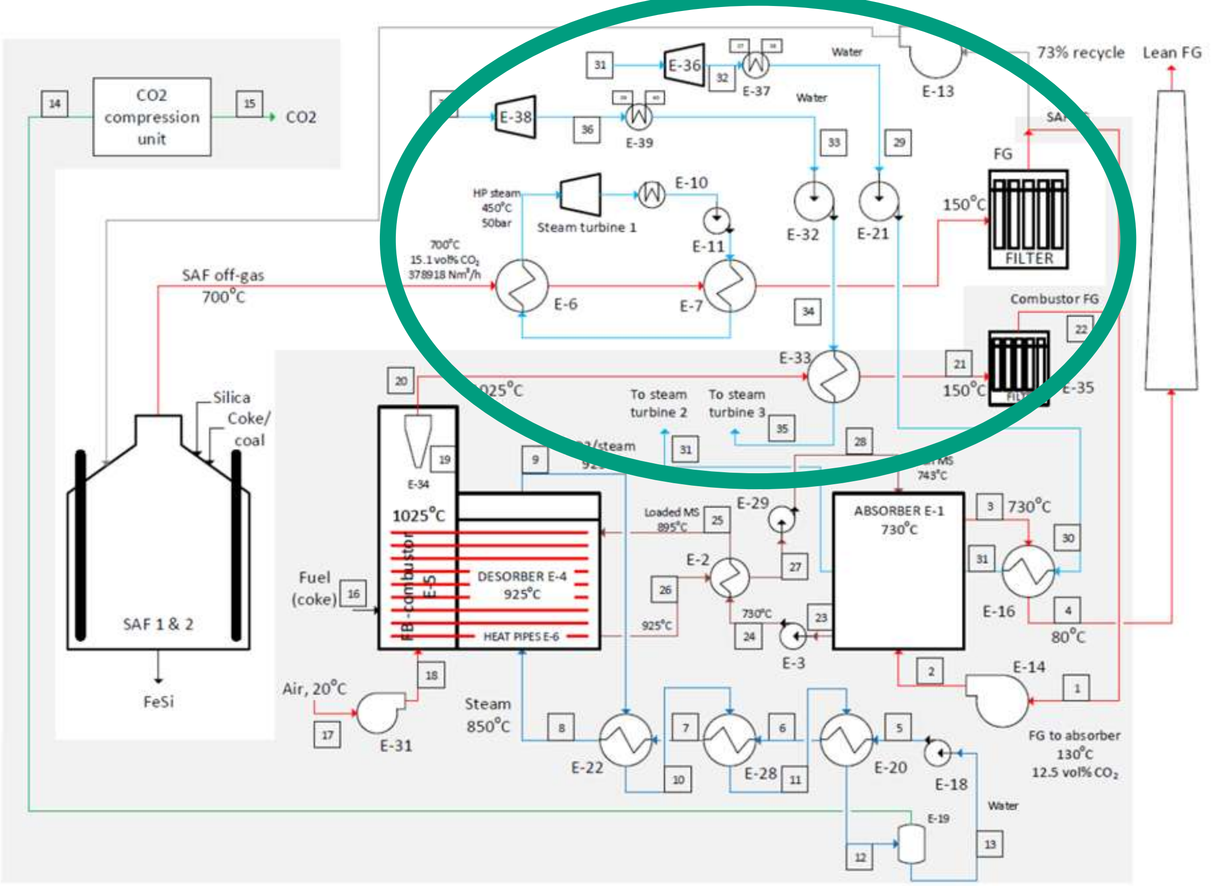
Further processing of CO_2

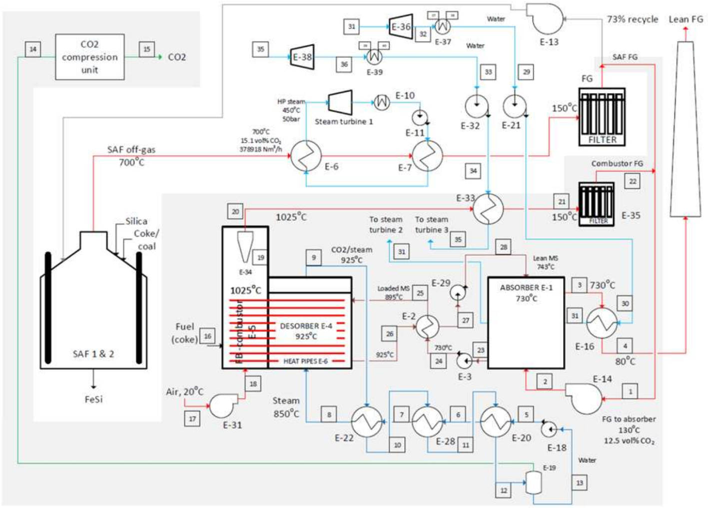
- CO_2 swept from desorber with superheated steam
- CO_2 and steam further separated by condensation
- Released CO_2 is further dried and compressed to standard conditions (20°C and 70bar)



Production of electricity

- High quality steam is produced through heat exchangers and additional electricity is generated through standard steam turbines





Cost estimation

CAPEX	Value / comment
Cost date	2018
Location	Generic, North-West Europe
Plant type	N^{th} of a Kind (NOAK), retrofitting
Plant site	Existing plant area (brown site)
Utilities	All utilities available (unit cost)
Access	Access to existing offices, control room, etc.
Materials	Stainless steel and high temperature materials
OPEX	**Value / comment**
Absorption medium	30 wt% CaO in molten $CaCl_2$-CaF_2
Organization	Operator (2 extra shifts + 3 day time, total 15 persons extra)
Coal price	80 EUR/tonne
Cost of electricity	40 EUR/MWh
Maintenance cost	4% of investment per year
Cost of cooling water	0.03 EUR/m^3
Economic	**Value / comment**
Rate of return	7.5%
Number of years	25 years
Number of operating hours	8760 h/year

- Estimate class 5, ±35%
- Detailed factor cost estimate method
- Equipment cost based on «Aspen In-plant» cost estimator and unit cost

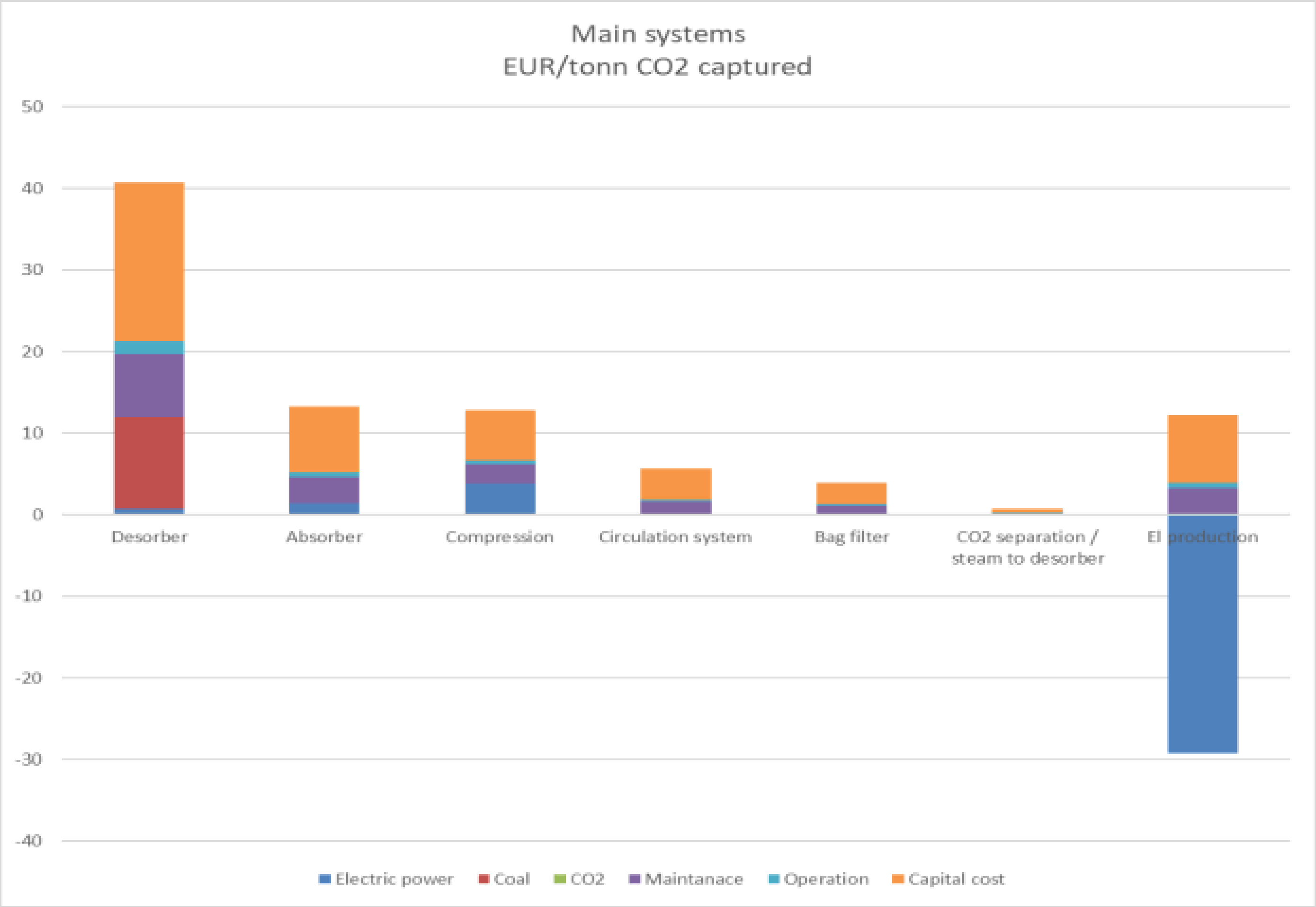
Cost estimation

- Summary of CAPEX, OPEX and capture cost

	CCMS
CAPEX [MEUR]	195
OPEX [MEUR / year]	5
Capture cost [EUR / tonne CO_2]	60

Costs divided per system

- Main cost driver is the **cost of desorption**



Conclusion

- Assuming that the capture system performs as anticipated, the results show **intersting promise** for using the CCMS technology for capturing CO_2 from metallurgical industry

- **Technical challenges** have been identified and will be adressed in further studies
  - Heat transfer in desorber
  - Material challenges due to high temperatures

Acknowledgements

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