CCS for industry emissions – the CEMCAP project

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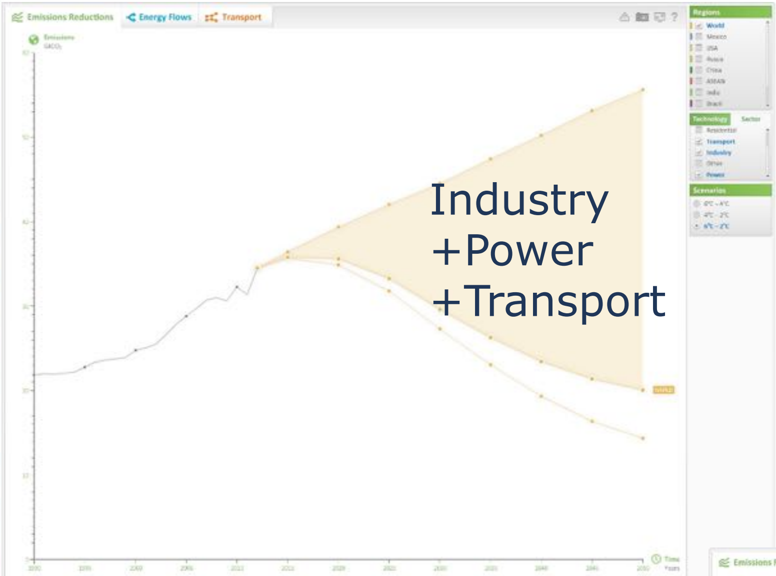
Outline

- Industrial CO_2 emissions in the IEA 2DS
- CO_2 emissions in cement industry
- The CEMCAP project
- Typical cement plant flue gas and CO_2 compositions
- Outlook on refineries and hydrogen production

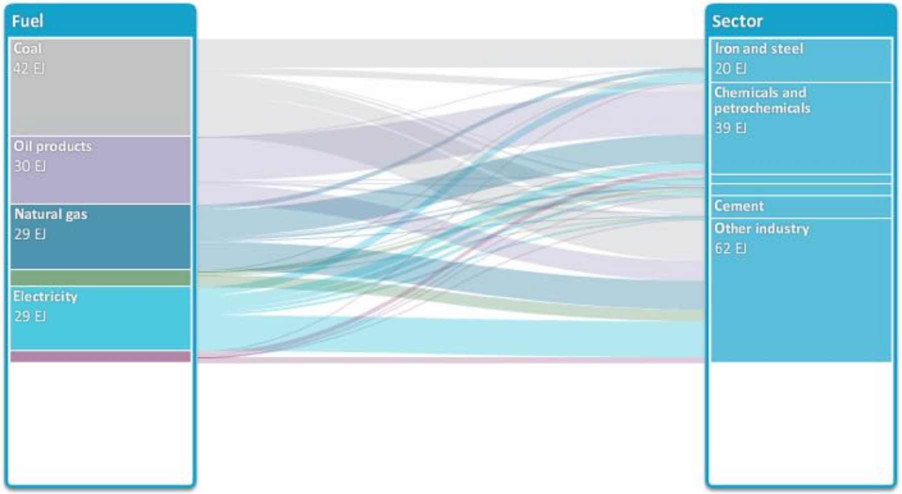
Where are emission reductions projected to come in 2050 IEA 2DS?



Contributions in 2050 to emissions reductions in 2DS:
Industry: 15%
Power: 52%
Transport: 19%

Charts generated with ETP2015 Data visualization http://www.iea.org/etp/explore/

Energy use in industry

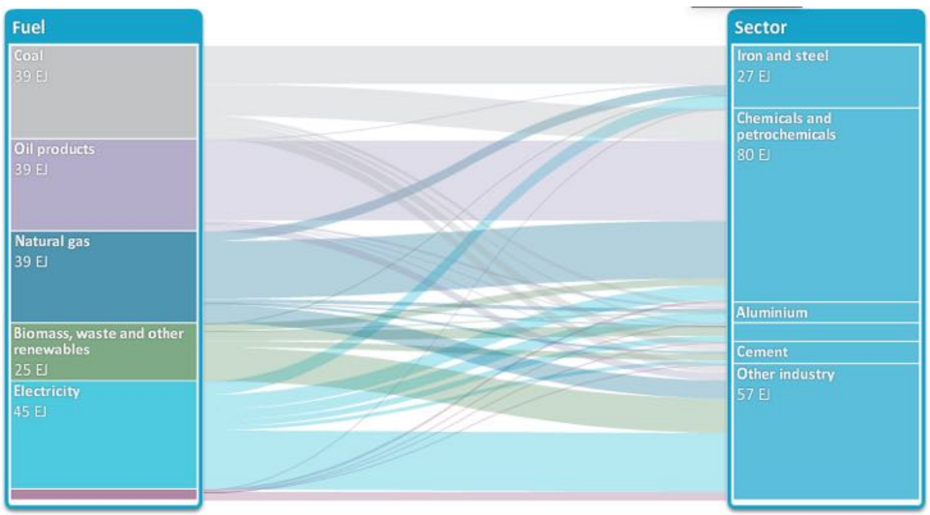


<u>2012</u>

- Iron and steel: 20 EJ
- Chemicals and petrochemicals: 39 EJ
- Cement: 11 EJ

<u>2050</u>

- Iron and steel: 27 EJ
- Chemicals and petrochemicals: 80 EJ
- Cement: 11 EJ



Change in fuel mix projected for cement industry towards 2050

Mainly a shift from coal to biomass, waste and other renewables

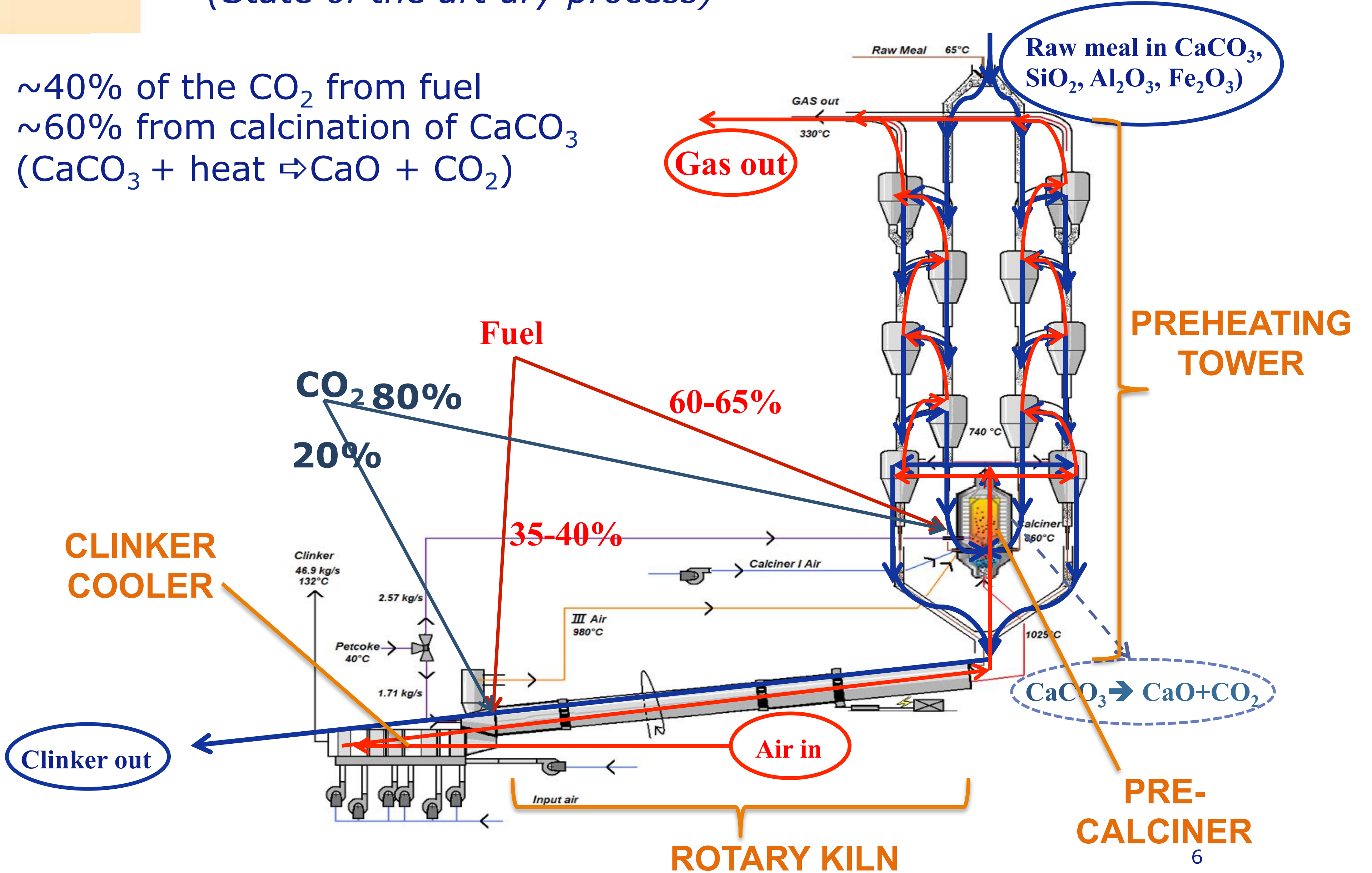
This shift is already ongoing in Europe.

- Fuel consumption does not give the full CO_2 emissions picture for cement plants
- Cement production currently accounts for ~5% of global anthropogenic CO_2 emissions

How does a modern cement plant work?

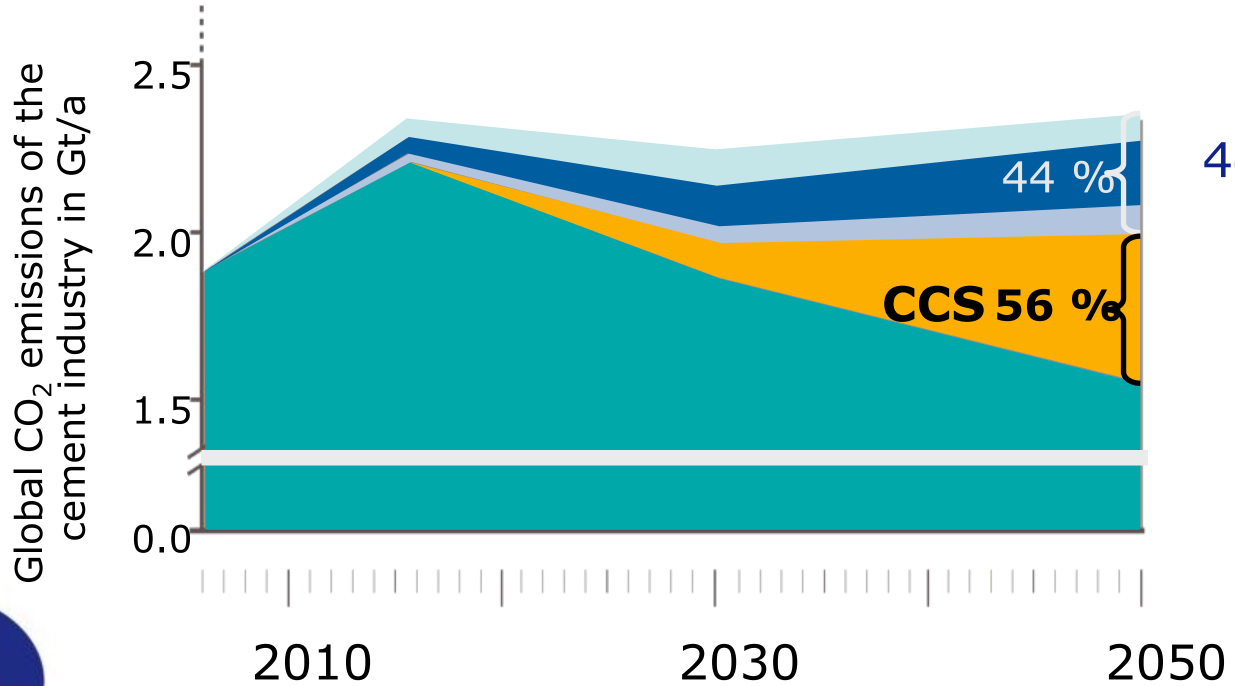
(State of the art dry process)

~40% of the CO_2 from fuel
~60% from calcination of $CaCO_3$
($CaCO_3$ + heat ⇨ $CaO + CO_2$)



The need for CCS in cement production

- IEA target for 2050: 50 % of all cement plants in Europe, Northern America, Australia and East Asia apply CCS
- Cement plants typically have a long lifetime (30-50 years or more) and very few (if any) are likely to be built in Europe → **Retrofit**



Source: IEA Cement Roadmap

44% Reduction by:

- Increase of energy efficiency
- Alternative fuels
- Reduction of clinker share

The CEMCAP project – CO_2 capture from cement production

The **primary objective of CEMCAP** is ***to prepare the ground for large-scale implementation of CO_2 capture in the European cement industry***

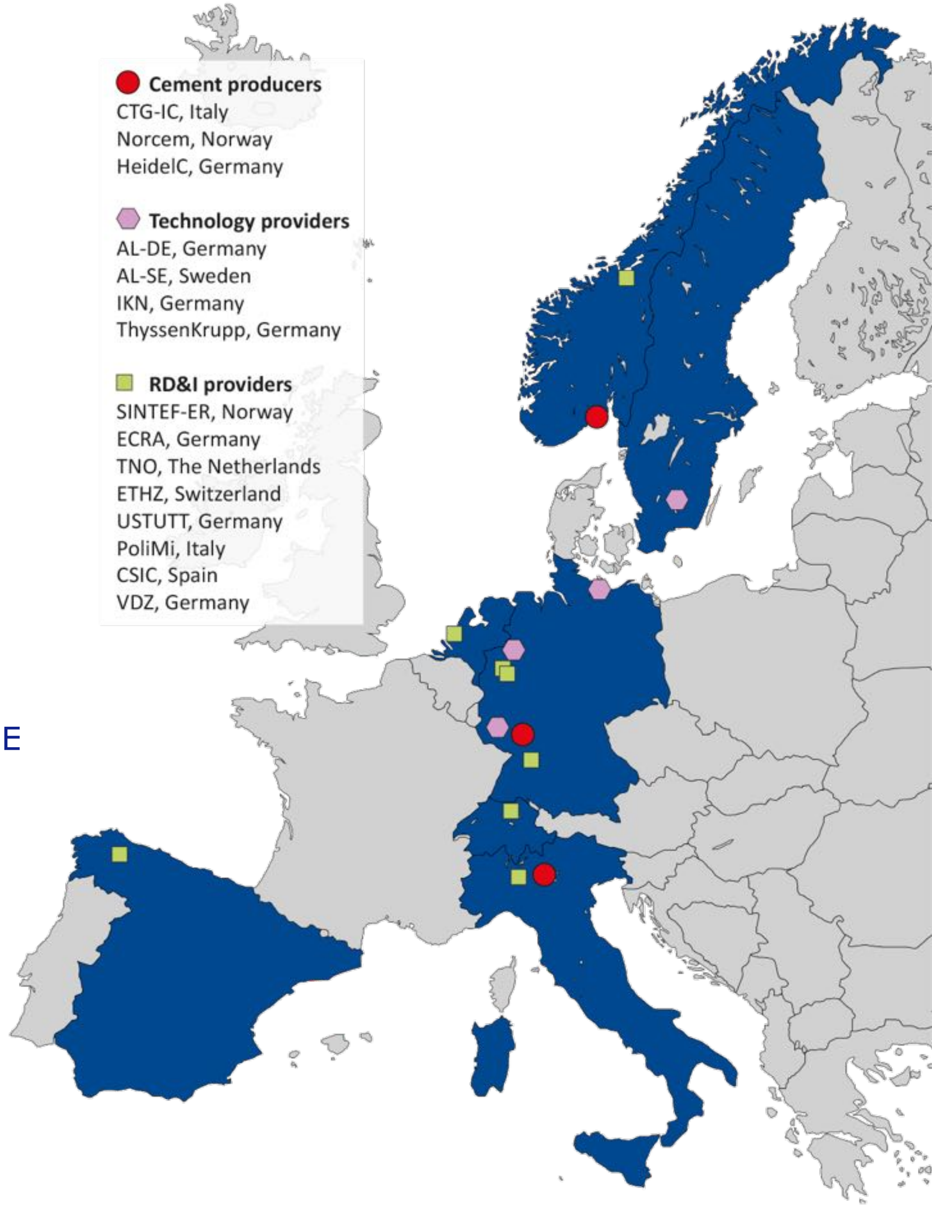
- Project coordinator: SINTEF Energy Research
- Duration: May 1st 2015 – October 31st 2018 (42 months)
- Budget: € 10 million
- EC contribution € 8.8 million
- Swiss government contribution: CHF 0.7 million
- Industrial financing ~€ 0.5 million
- Number of partners: 15

CEMCAP Consortium

Cement Producers
CTG (Group Technical Centre of Italcementi), IT
Norcem, NO
HeidelbergCement, DE

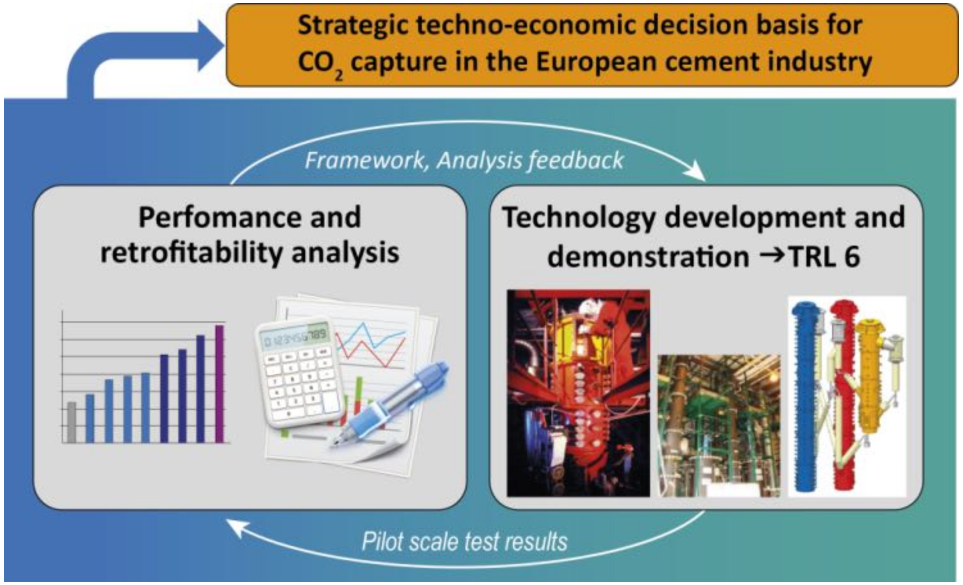
Technology Providers
Alstom Carbon Capture* (AL-DE), DE
Alstom Power Sweden* (AL-SE), SE
IKN, DE
ThyssenKrupp Industrial Solutions, DE

Research Partners
SINTEF Energy Research, NO
ECRA (European Cement Research Academy), DE
TNO, NL
EHTZ, CH
University of Stuttgart, DE
Politecnico di Milano, IT
CSIC, ES
VDZ, DE



*Aquired by GE Power, names will change

CEMCAP approach: iteration between analytical and experimental research



<u>Analytical research</u>

Capture process simulations

Simulations of cement plants with CO_2 capture

Cost estimations/benchmarking

Retrofitability analysis

CCU for cement

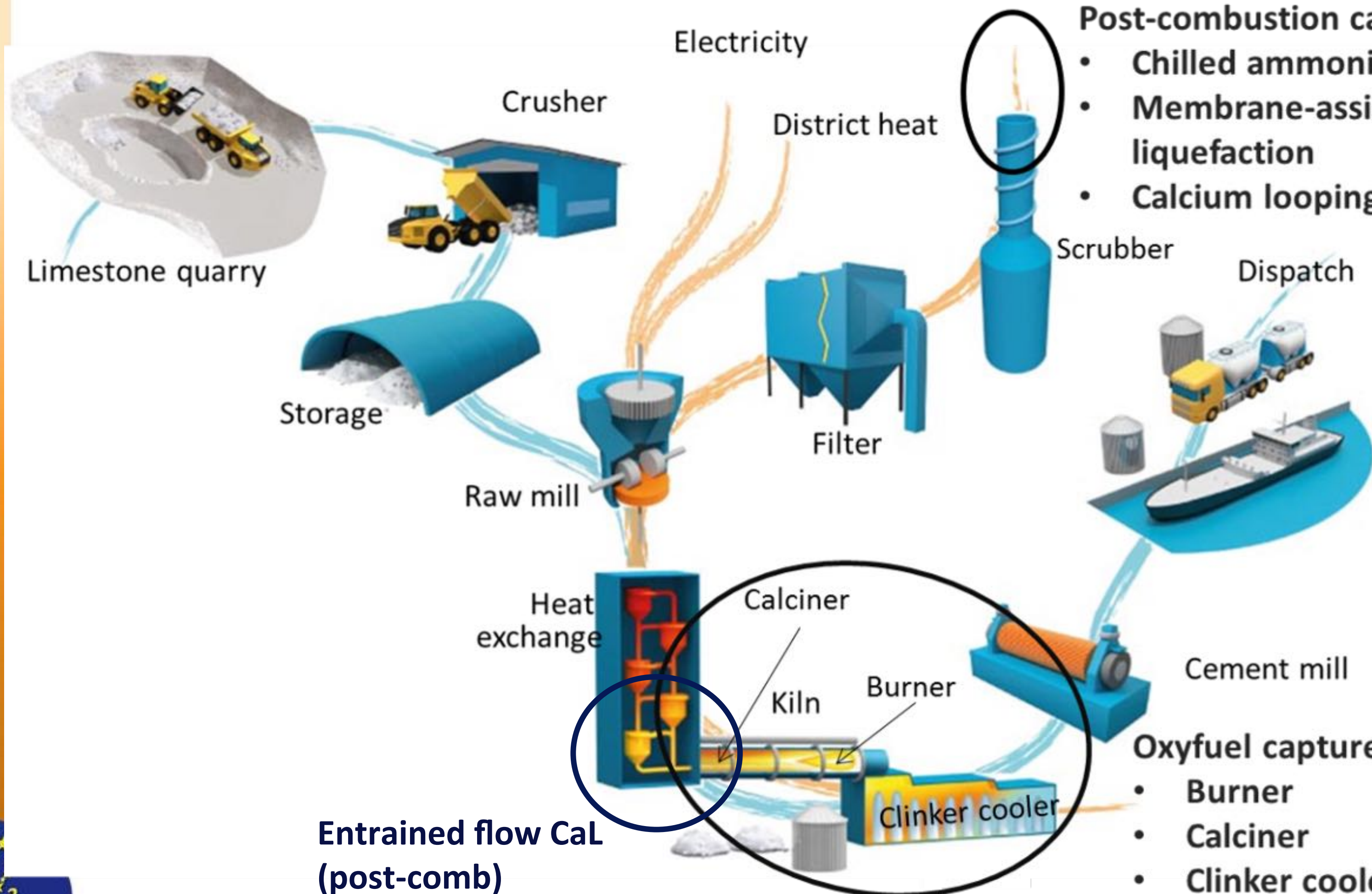
<u>Experimental research</u>

Testing of three components for oxyfuel capture

Testing of three different post-combustion capture technologies

~10 different experimental rigs

Technologies to be tested in CEMCAP



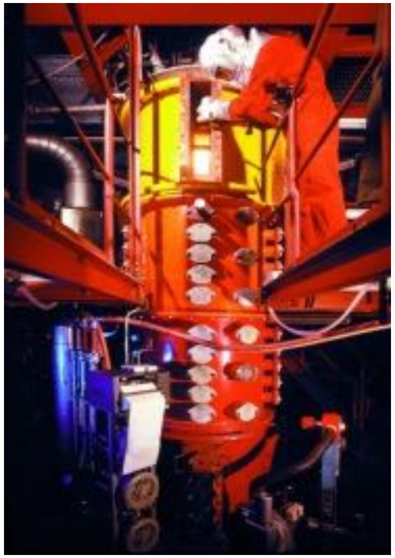
Post-combustion capture tests:
- **Chilled ammonia (CAP)**
- **Membrane-assisted CO_2 liquefaction**
- **Calcium looping (CaL)**

Entrained flow CaL (post-comb)

Oxyfuel capture tests:
- **Burner**
- **Calciner**
- **Clinker cooler**

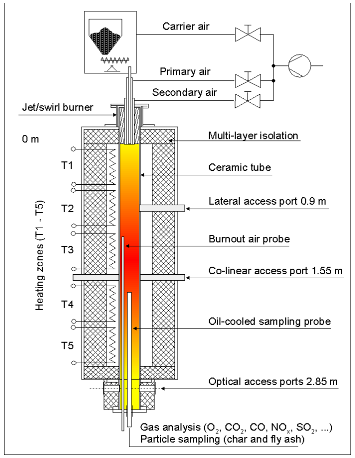
Technologies to be tested - oxyfuel

<u>Oxyfuel burner</u>
Existing 500 kWth oxyfuel rig at USTUTT is being modified for CEMCAP



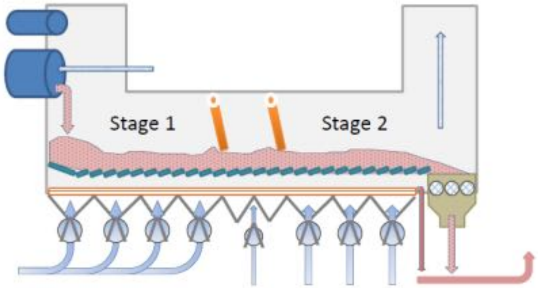
Partners: USTUTT, TKIS, SINTEF-ER

<u>Calciner test rig</u>
Existing <50 kWth entrained flow calciner (USTUTT) will be used for oxyfuel calcination tests



Partners: USTUTT, VDZ, IKN, CTG

<u>Clinker cooler</u>
Construction finished, will be installed for on-site testing at HeidelbergCement in Hannover (summer 2016)



Partners: IKN, HeidelC, VDZ

Technologies to be tested – post-combustion capture

Chilled Ammonia Process (CAP)

Pilot tests at GE Power Sweden (never tested for such high CO_2 concentrations before, up till 35%)

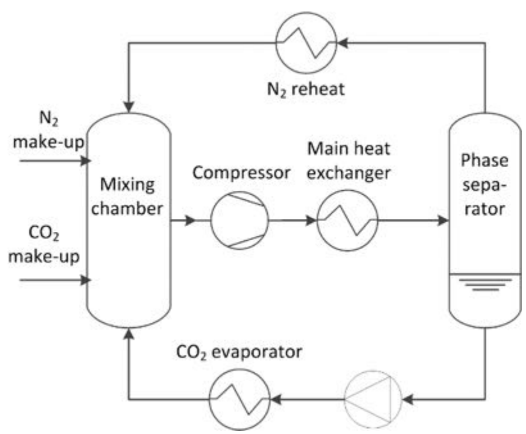
Partners: ETHZ, GE-SE, GE-DE

Membrane assisted CO_2 liquefaction

Novel concept, suitable for high CO_2 concentrations

Membrane tests: TNO

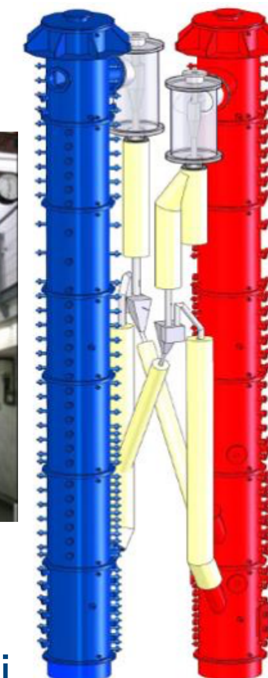
Liquef. tests: SINTEF-ER



Partners: TNO, SINTEF-ER

Ca-looping

End-of pipe CaL as well as integrated CaL is developed



Partners: USTUTT, CTG, PoliMi, CSIC, IKN

CEMCAP techs differ in many ways

	Oxyfuel capture	Post combustion capture technologies		
		Chilled ammonia	Membrane-assisted CO_2 liquefaction	Calcium Looping
CO_2 capture principle	Combustion in oxygen (not air) gives a CO_2-rich exhaust	NH_3/water mixture used as liquid solvent, regenerated through heat addition	Polymeric membrane for exhaust CO_2 enrichment followed by CO_2 liquefaction	CaO reacts with CO_2 to from $CaCO_3$, which is regenerated through heat addition
Cement plant integration	Retrofit possible through modification of burner and clinker cooler	Retrofit appears simple, minor modifications required for heat integration	No cement plant modifications. Upstream SOx, NOx, H_2O removal required	Waste from capture process (CaO) is cement plant raw material
Clinker quality	Maintained quality must be confirmed	Unchanged	Unchanged	Clinker quality is very likely to be maintained
CO_2 purity and capture rate	CO_2 purification unit (CPU) needed. High capture rate and CO_2 purity possible (trade-off against power consumption).	Very high CO_2 purity, can also capture NOx, SOx. High capture rate possible.	High CO_2 purity (minor CO_2 impurities present). Trade-off between power consumption and CO_2 purity and capture rate.	Rather high CO_2 purity (minor/ moderate CO_2 impurities present). High capture rate.
Energy integration	Fuel demand unchanged. Waste heat recovery + electric power increase.	Auxiliary boiler required + waste heat recovery. Electricity for chilling.	Increase in electric power consumption, no heat integration.	Additional fuel required, enables low-emission electricity generation.

Flue gas characteristics – CO_2 emissions

Component	Exhaust gas			
	Conventional	From oxyfuel combustion		From Post-combustion*
		Min	Max	
CO_2	14 – 35 vol. %	95 vol.%	99.9 vol.%	> 99.0 vol.%
O_2	3 – 14 vol.%	1.2 vol.%	0.001 vol.%	
N_2	Rest	3.4 vol.%	-	
Ar		0.4 vol.%	-	
NO_x	0. 5 – 0.8 g/m³	< 0.55 g/m³	< 0.55 g/m³	
SO_2	50 – 400 mg/m³	< 4 mg/m³	< 4 mg/m³	
CO	0.1 – 2 g/m³	< 0.3 g/m³	-	
H_2O	6 – 10 vol.%	-	-	
HCl	< 20 mg/m³	-	-	

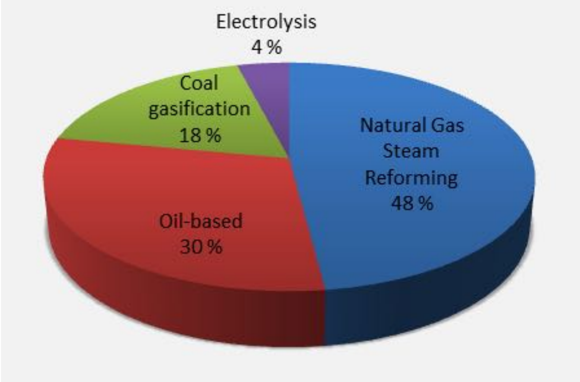
*to be verified for Ca-looping capture

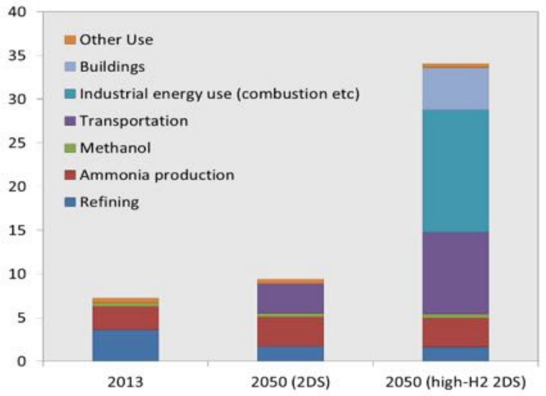
CO_2 capture from refineries

- Emission sources: **10-25 stacks** depending on the complexity of the refinery
  - Fired heaters contribute from 40-60% of the emissions
  - Also hydrogen production, combined heat and power and the FCC unit.
- The overall capture rate for a refinery is considerably lower than 90% due to the distributed nature of emissions
  - End-of-pipe capture using **amine technology** is uneconomical for small emission sources
- CO_2 capture from syngas stream in the Steam Methane Reformer (SMR) process for hydrogen production is the most economical option for capture in a refinery
  - **Solvent based capture** at relatively high partial pressure
  - Around 50-60% of overall CO_2 emissions from hydrogen production can be captured
- **Oxy-fired FCC** process is considered for CO_2 removal from the FCC process
  - Has implications on product performance and hence downstream processes
- To overcome the distributed nature for end-of-pipe capture:
  - **Hydrogen combustion** in fired heaters in place of refinery fuel gas ⇨CO_2 capture from a single source of hydrogen production

H_2 production with CO_2 capture

- Current global H_2 production:
  - Mainly fossil-fuel based
  - ~7.7 EJ/year
  - Related emissions: ~500 Mt of CO_2/year
- IEA **High H2 2DS** envisages by 2050:
  - ~35 EJ H_2/year
  - Use of H_2 for transport, industry, buildings, energy
- Assuming costs for CO_2 emissions, IEA envisage in US, EU4* and Japan by 2050:
  - 12-38% H_2 from renewable electricity and biomass
  - 58-81% H_2 from fossil fuels with CCS
- "Pre-combustion" separation technologies (absorption, adsorption, membranes, phase separation) can be combined to meet the purity requirements on H_2 and CO_2
- Trade-offs between energy efficiency, purity requirements, product yield…





*Germany, Italy, France, UK

Concluding remarks

- Curbing of industrial CO_2 emissions from cement will require CCS in order to contribute to reaching the 2 or 1.5 degree target
- Existing capture technologies are being developed and tested in CEMCAP for cement plant retrofit
- The composition of the captured CO_2 will vary depending on capture technology and process design
- From IMPACTS: There is no easy, one-size-fits-all solution for how a CCS chain should be designed and how to set the limits for the concentrations of impurities.
- Good communication is required between the different actors along the CCS chain to identify the requirements on CO_2 composition.
  - Trade-offs between energy consumption, cost and purity.
- Showstopper components/mixtures identified for transport or storage? Alert the CO_2 capture part of the CCS chain!

Thank you for your attention!

Acknowledgement

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