european cement research academy

Carbon Dioxide Control Technologies for the Cement Industry

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GCEP Workshop “Carbon Management in Manufacturing Industries”

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Carbon Dioxide Control Technologies for the Cement Industry

1. Introduction
2. The cement clinker burning process
3. Assessment of carbon dioxide control technologies
   3.1 Pre-combustion technologies
   3.2 Oxyfuel technology
   3.3 Post-combustion technologies
4. Preliminary research results (Oxyfuel technology)
   4.1 Impact on raw meal decarbonation
   4.2 Modeling of the clinker burning process with Oxyfuel operation

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The German Cement Works Association (VDZ)

↑ The Research Institute of the Cement Industry, Düsseldorf / Germany

Activities:

- Mortar and concrete
- Chemistry and mineralogy
- Environmental expertise
- Plant technology investigations
- Environmental measurements
- Certification
- Knowledge transfer

The European Cement Research Academy (ECRA)

- has been founded by VDZ in 2004
- Members (> 40) are cement companies and associations from Europe, Asia, Australia, US

- objectives
  - → know how transfer
  - → joint research

- activities
  - → seminars and workshops
  - → research programmes
    - - carbon capture technologies for the cement industry
    - - continuous measurement of biomass CO_2 in stack gases

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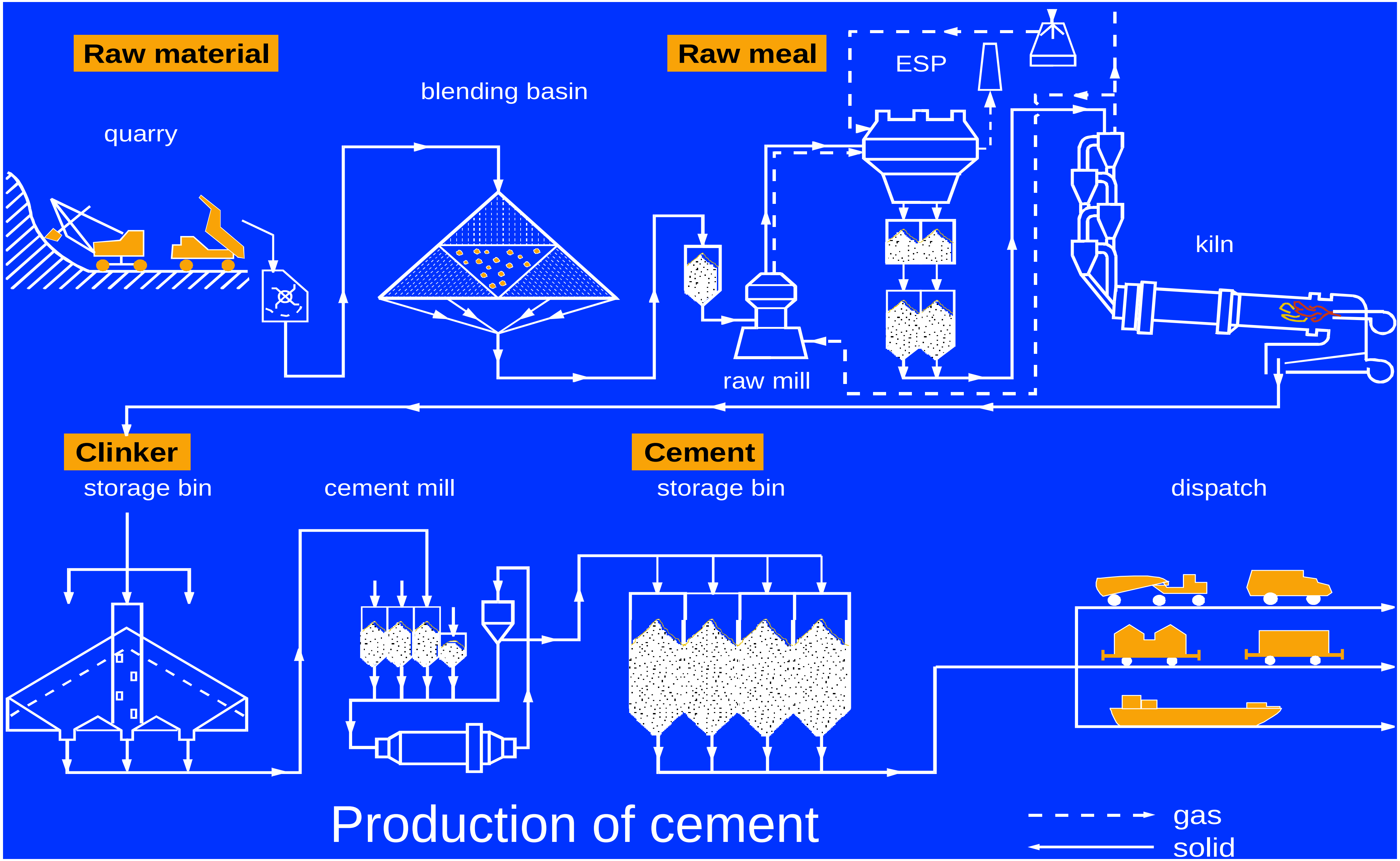

Raw material
quarry
blending basin
Raw meal
ESP
raw mill
kiln
Clinker
storage bin
cement mill
Cement
storage bin
dispatch
Production of cement
gas
solid

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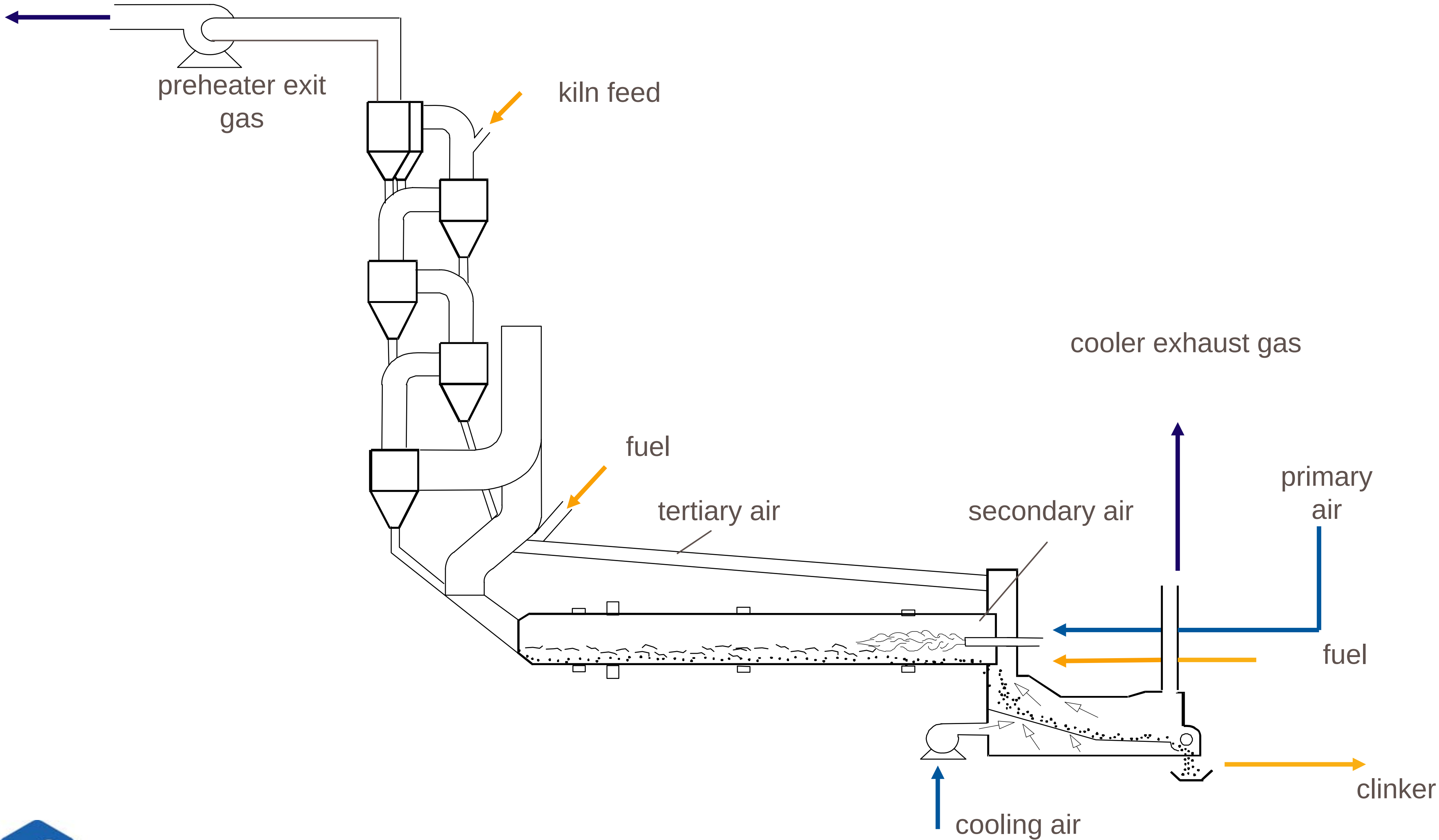
Clinker burning process



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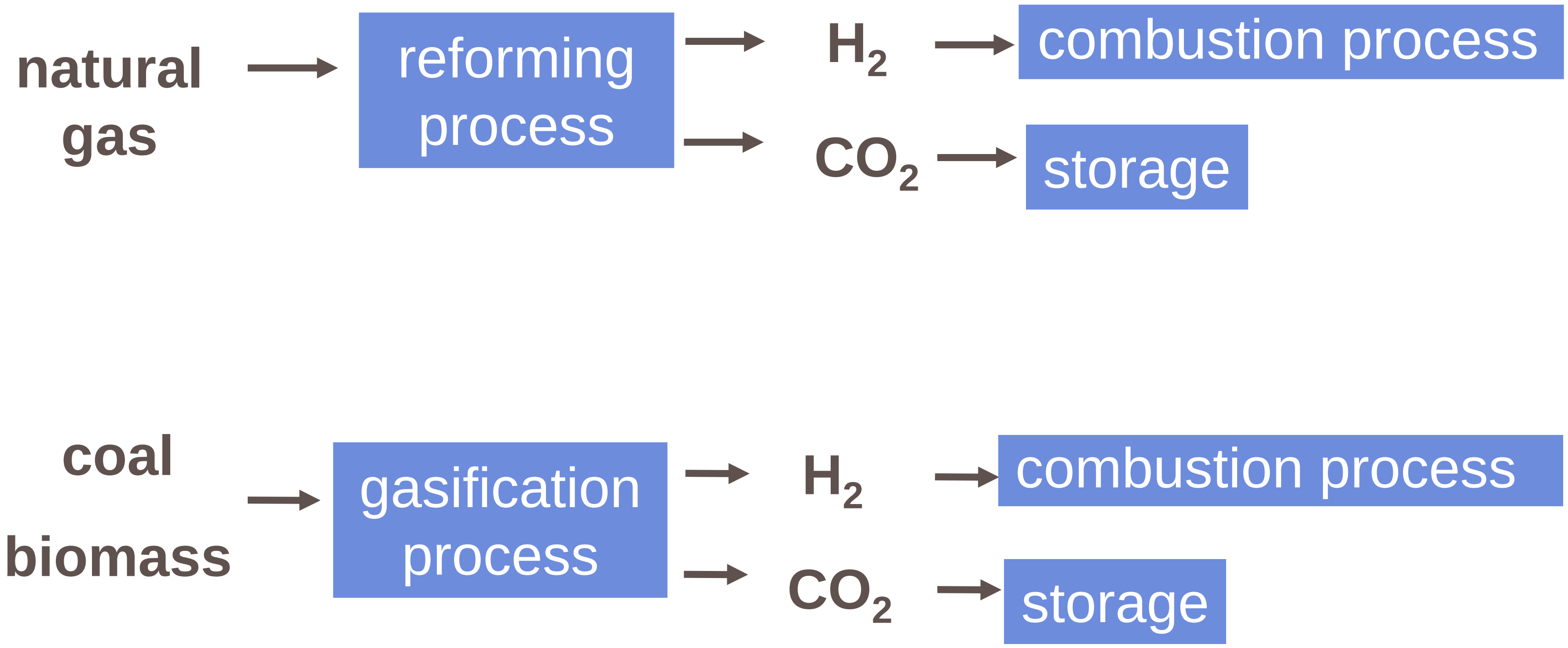
3.1 Pre-combustion technologies



Scheme of gasification process

- Partial oxidation for heat supply

  $CH_4 + ½\, O_2 \rightarrow CO + H_2$

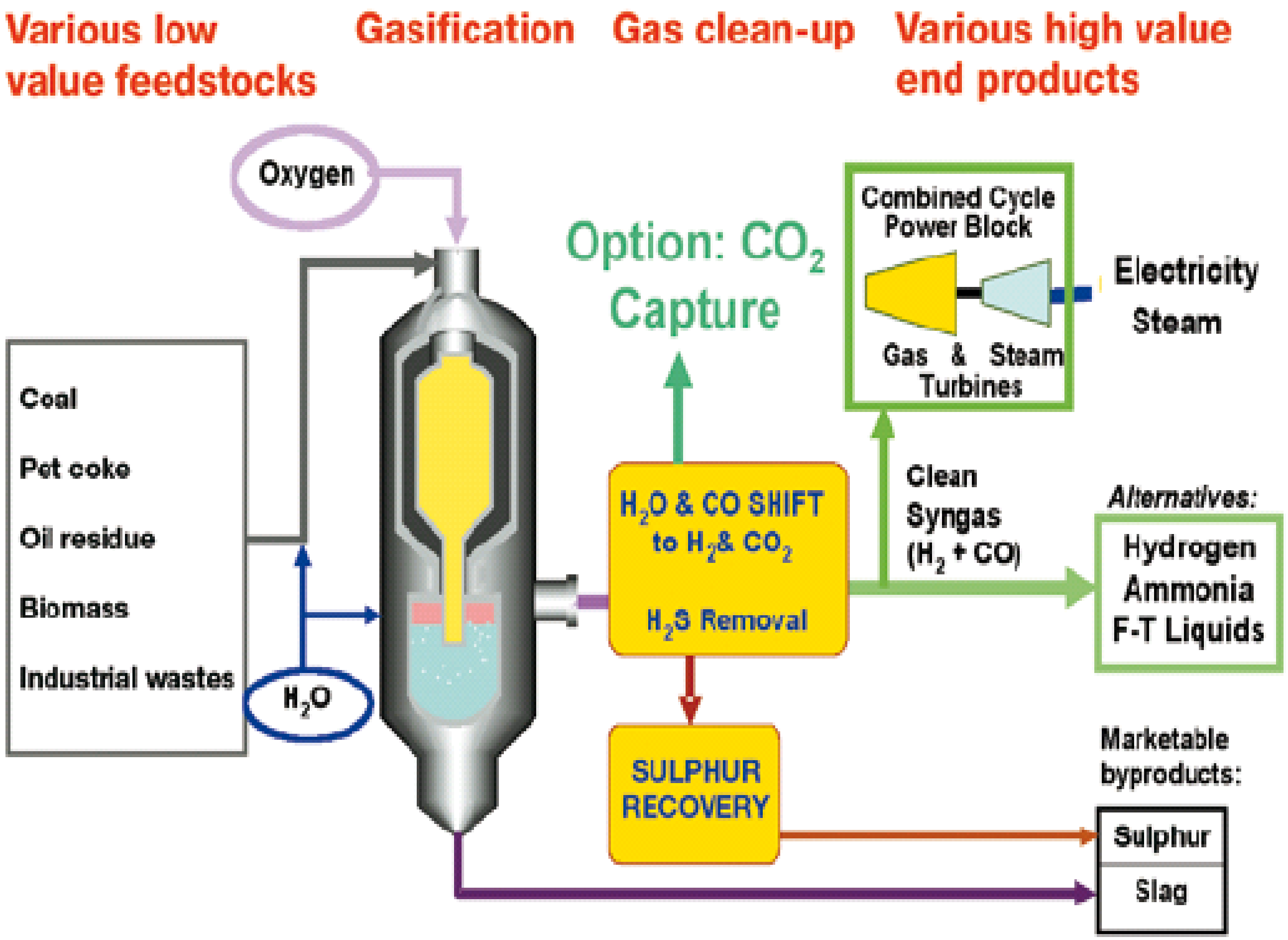
- Gasification of solid carbonaceous matter

  $2\, C + O_2 \rightarrow 2\, CO$

  $C + H_2O \rightarrow CO + H_2$

- CO shift for hydrogen synthesis

  $CO + H_2O \rightarrow CO_2 + H_2$



Pre-combustion technologies: level of implementation

- Steam reforming is the predominant technology for H_2 production worldwide
- IGCC (**I**ntegrated **G**asification **C**ombined **C**ycle) demonstration plants since the 1970s
- IGCC can be realized with or without CO_2 capture
- Today no IGCC plant with capture technology in operation
- Two IGCC projects planned with CO_2 capture:
  - Australia (100 MW)
  - Germany (450 MW)
- CO_2 capture costs for new IGCC plant: 13-37 \$/t CO_2 (CO_2 capture by physical absorption)

Gasification of coal and petcoke for power generation - Puertollano IGCC Power Plant (Spain)

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Applicability of pre-combustion technologies to clinker burning process (1)

Hydrogen from syngas of gasification processes as fuel for cement kiln burners?

- Hydrogen has different properties as actual fuels:
  - handling/feeding must be solved
  - pure H_2 cannot be used in kiln firing
- H_2 flames have low heat transfer by radiation
  - temperature profile in the kiln
  - injection of raw meal or clinker dust

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Applicability of pre-combustion technologies to clinker burning process (2)

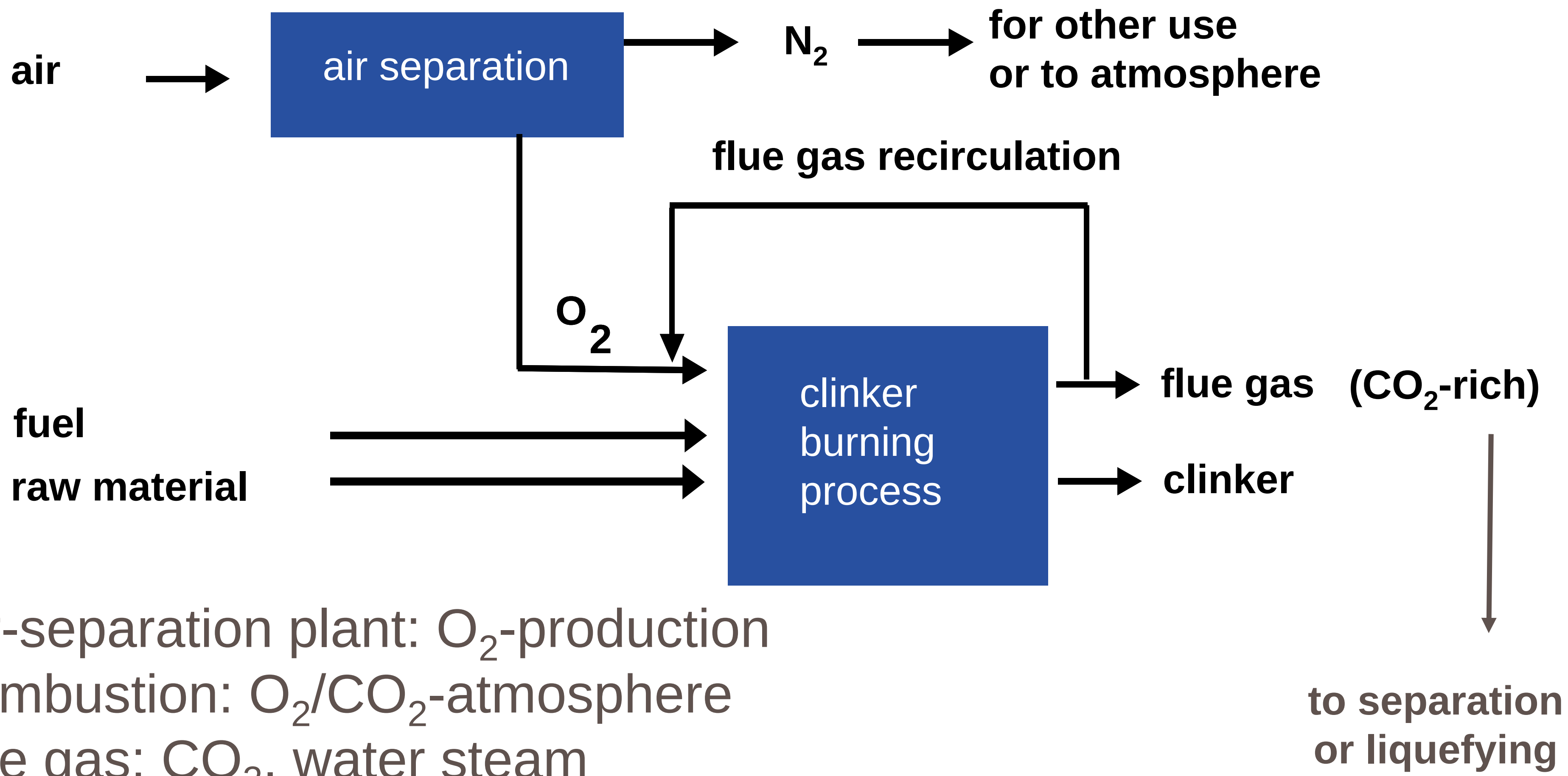
Hydrogen from syngas of gasification processes as fuel for cement kiln burners?

- New combustion technologies required:
  - non-carbonaceous flame ingredients
  - new burner technologies
    for increasing heat transfer

- Only abatement of fuel CO_2
  → only 1/3 of CO_2 emission is
  captured

→ hardly promising for clinker burning process

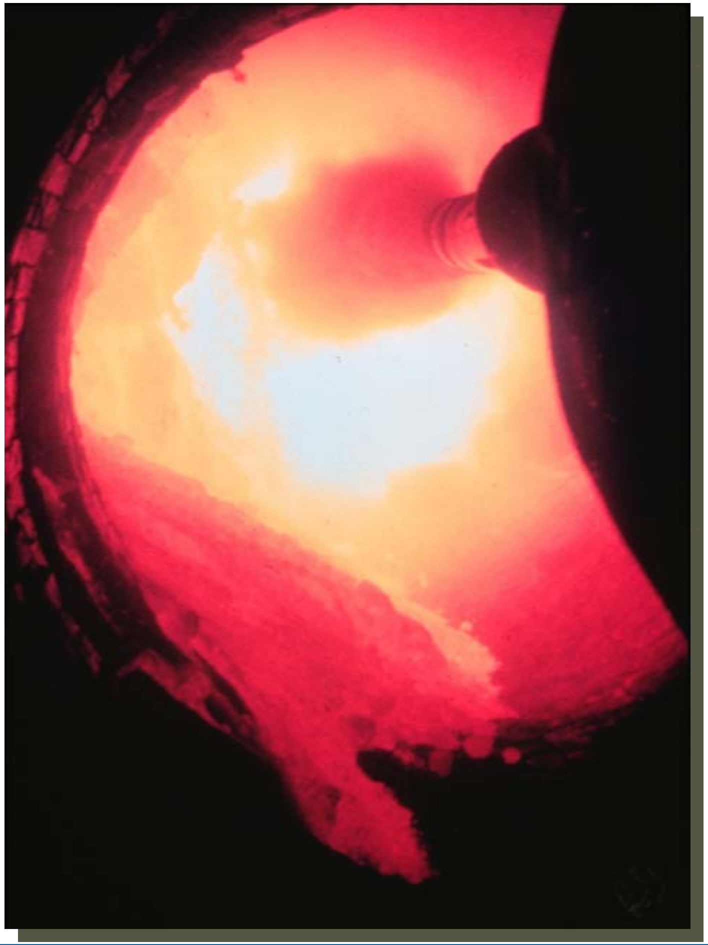
3.2 Oxy-fuel Technology



- air-separation plant: O_2-production
- combustion: O_2/CO_2-atmosphere
- flue gas: CO_2, water steam

Applicability of oxy-fuel technology to clinker burning process

- Oxygen production by air separation is state of the art (by freezing or membranes)
- Oxy-fuel technology is state of the art in other industries, e.g. for glass production
- New combustion technologies required, e.g.:
  - Oxy-fuel burner
  - Waste gas recirculation
- Modifications of plant design, e.g.
  - Dimensions of kiln, cooler, preheater
  - Gas recirculation including dedusting, cooling
- Impact on reactions (e.g. decarbonation) and clinker quality



3.3 Post-combustion technologies

- Absorption technologies:

  - chemical absorption (Econamine®; Benfield®, etc.)

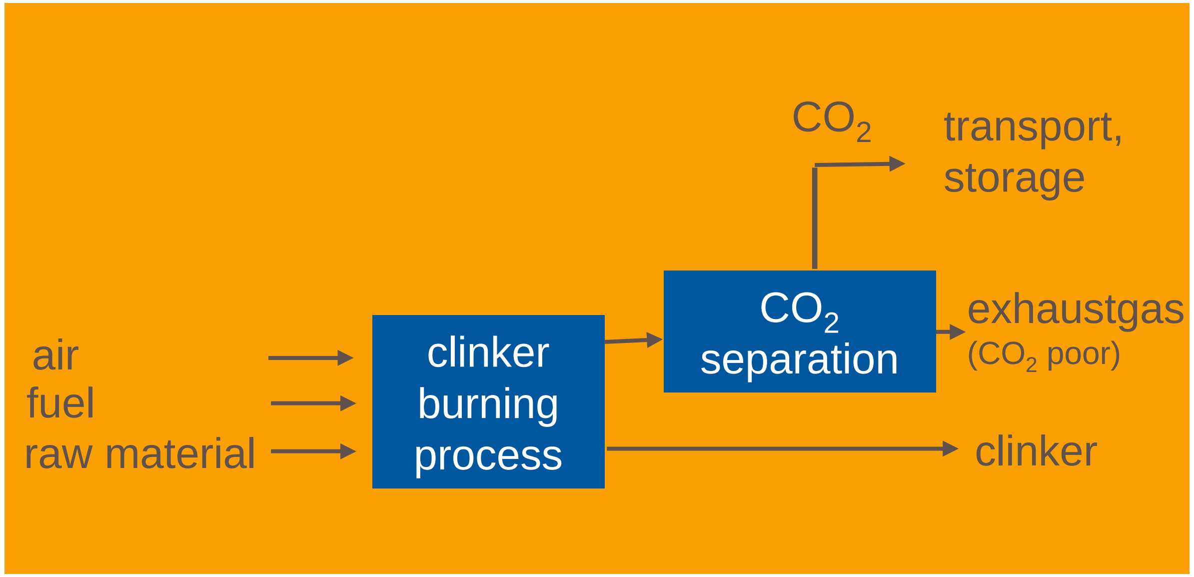
  - physical absorption (Selexol®, Rectisol®, etc.)

- Membrane processes
- Solid sorbent processes

  - physisorption processes

  - mineral carbonation

  - carbonate looping



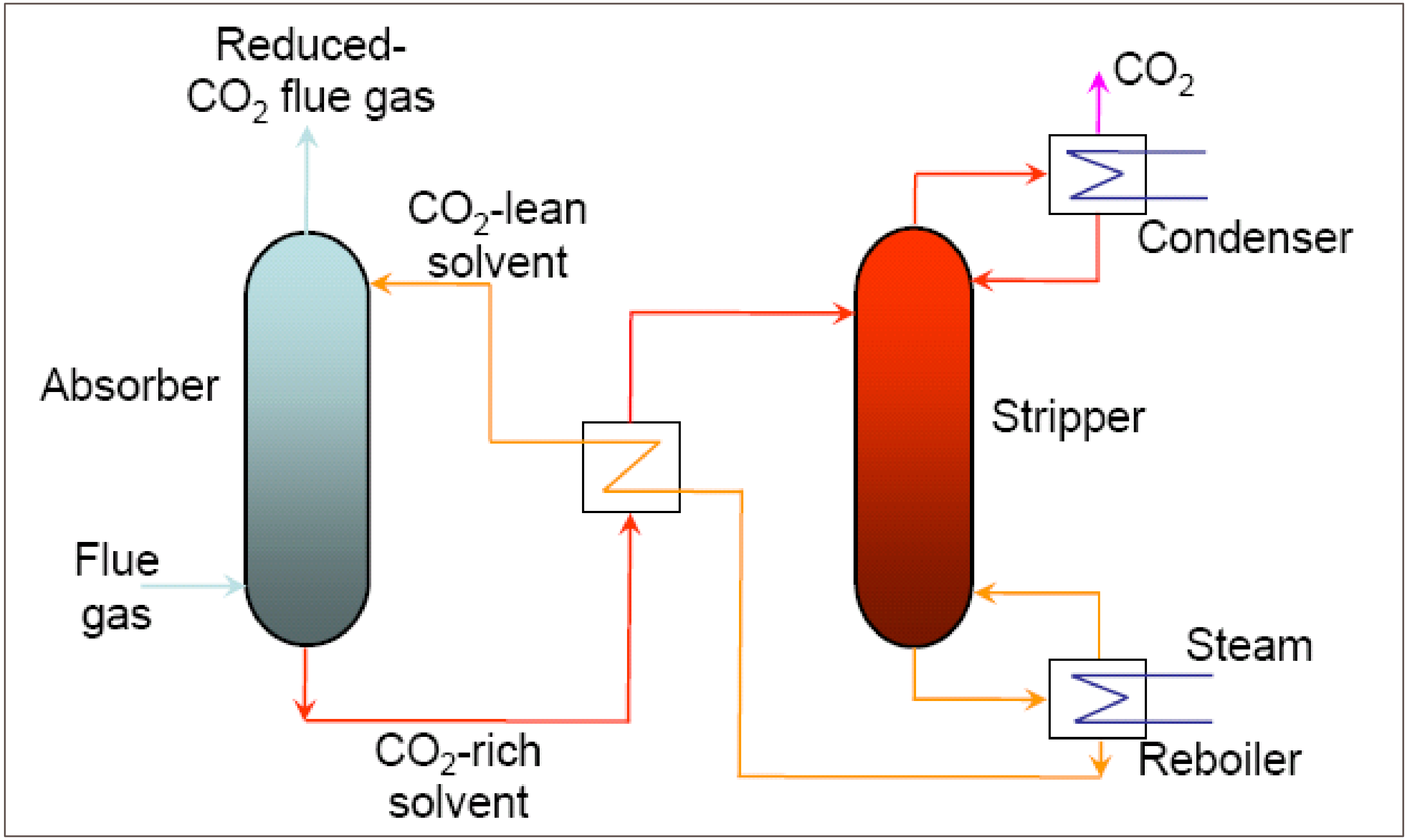
→ the higher the CO_2 concentration the higher the capture efficiency
→ end-of-pipe technologies; retrofit to existing plants possible

Absorption technologies are most developed today

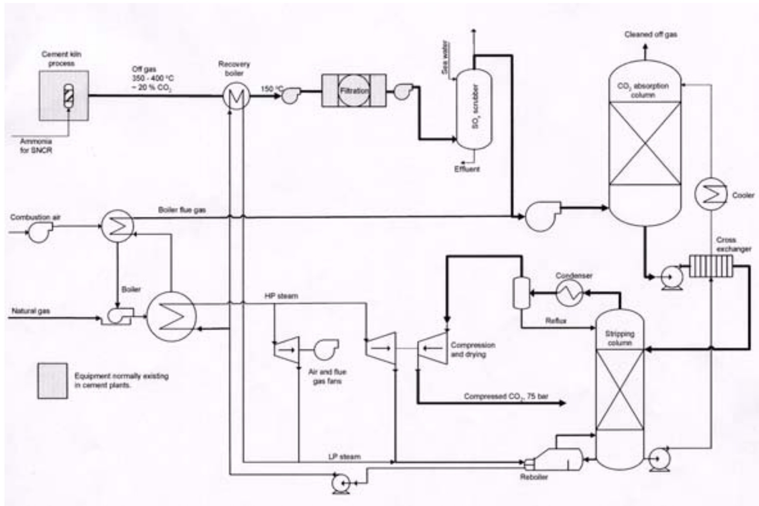
- Chemical absorption:
  - amines (e.g. MEA) or inorganic salt solutions (e.g. K_2CO_3) as absorbent
  - high energy demand for solvent regeneration
  - very low dust, SO_2 and NO_2 concentration required
  - CO_2 capture costs for new coal-fired power plants: 29-51 $/t CO_2
- Physical absorption:
  - solvents as absorbent (e.g. methanol)
  - high CO_2 content required

↑ CO_2 capture by chemical absorption (fertilizer plant in Malaysia)

Simplified flow sheet of chemical absorption process for CO_2 capture



Application of CO_2 capture with amine absorption in a Norwegian 3000 t/d cement plant (pilot study)



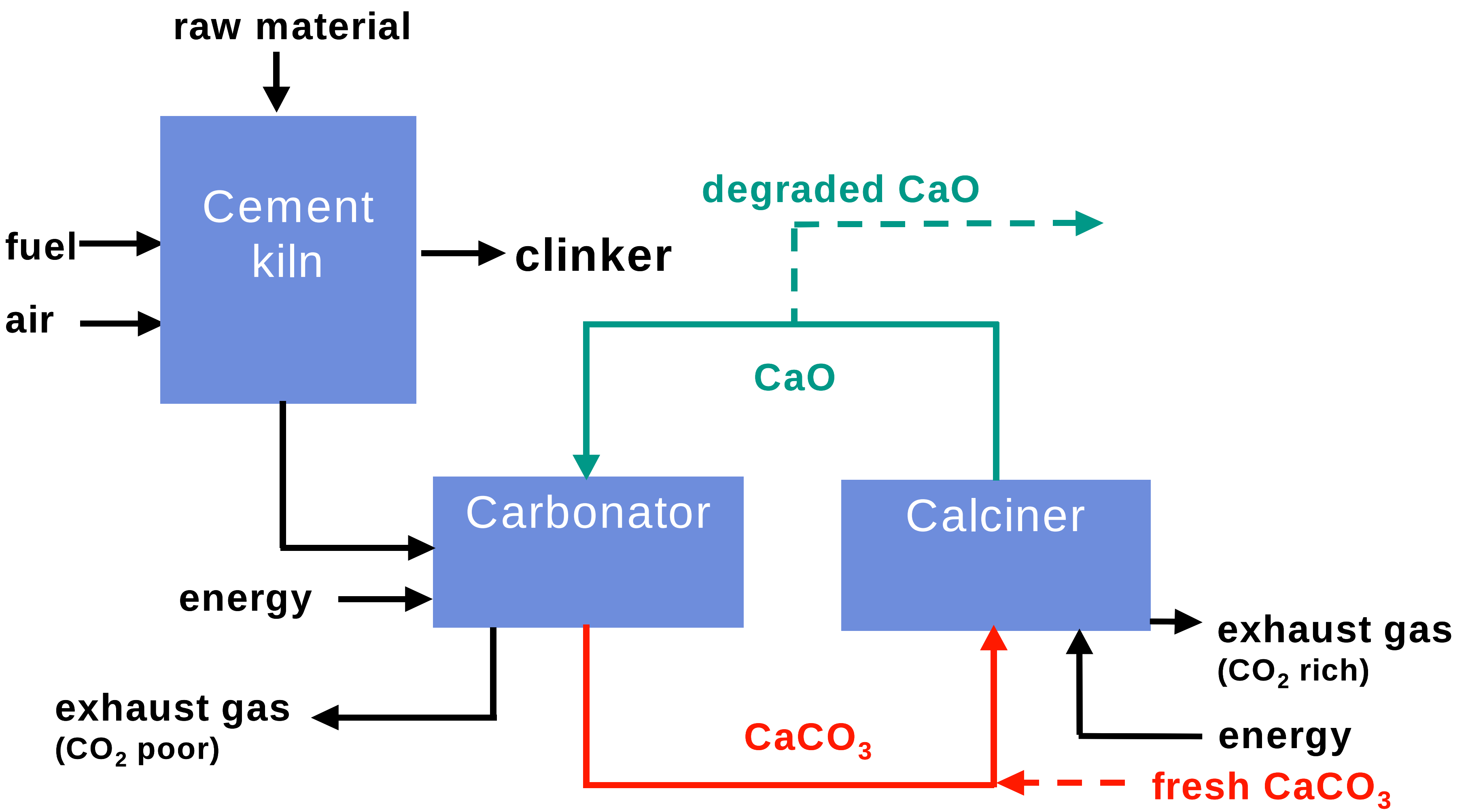
Technical requirements

- NO_x abatement with SNCR
- SO_2 abatement with wet scrubber
- waste heat recovery boiler
- CO_2 capture amine absorption
- Amine recovery with stripper
- Gas fired boiler

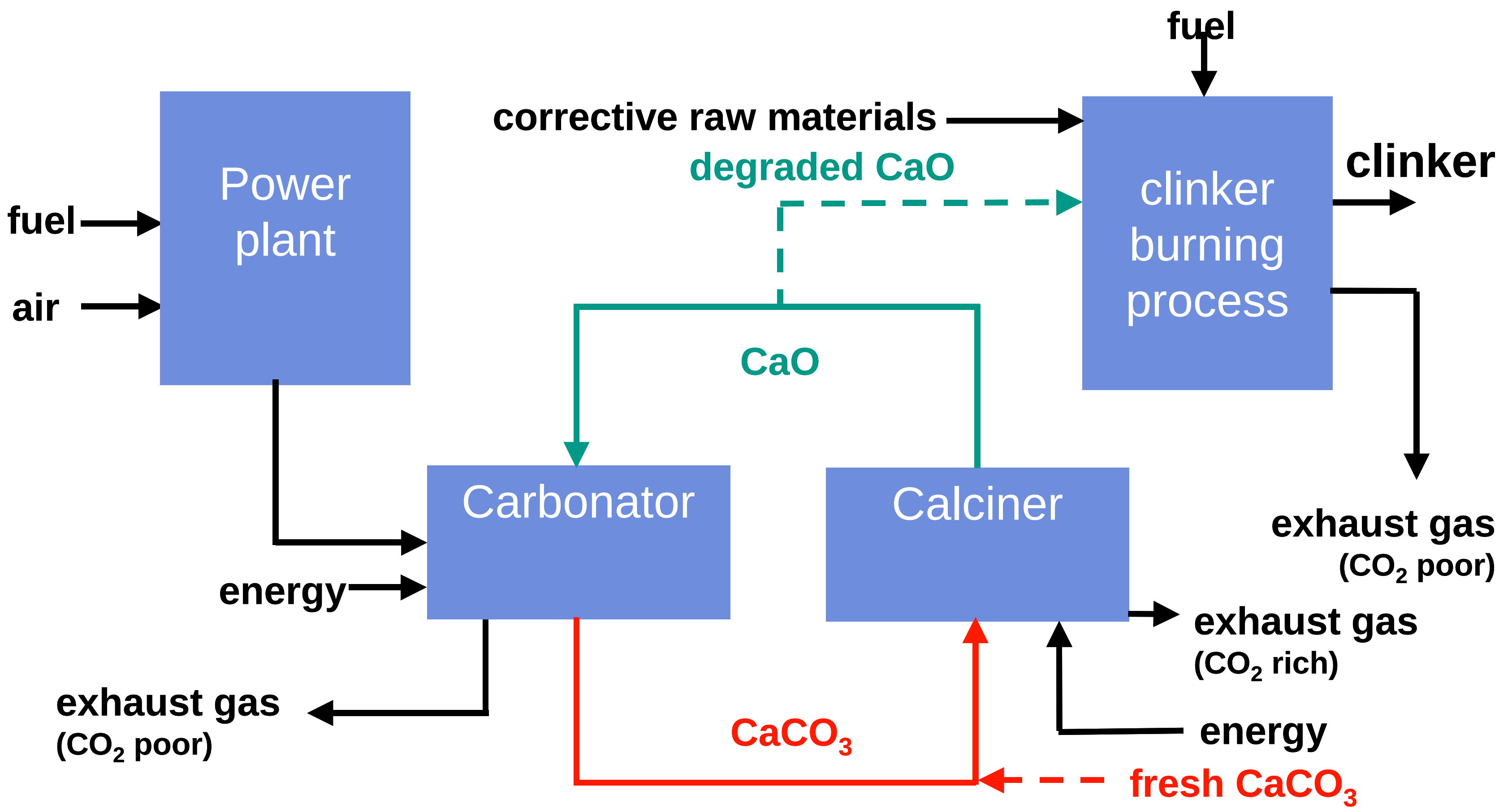
Investment costs in mio €	**110**
thereof:	
- waste gas cleaning	8
- waste heat recovery boiler	7
- CO_2 capture	32
- CO_2 drying and compression	28
- boiler	28
Operating costs in mio €/year	**32**
Total costs in €/t CO_2	**45**

2006 data

Carbonate looping



Synergy of cement and power plants



One 3,000 tpd kiln utilizes degraded sorbent (after 30 loops) of three 800 $MW_{el.}$ power plants.

Assessment of CO_2 capture technologies

capture technology	availability on scale			applicability in the cement industry	reduction of
	research	demo	industrial		
Pre-Combustion					
- reforming / gasification	X	X	X	yes (new kilns)	only fuel CO_2
Oxyfuel	X		(X)	yes (new kilns)	fuel and process CO_2
Post-Combustion					
- absorption	X	X	X	yes (process re-design)	fuel and process CO_2
- membranes	X		(X)	?	fuel and process CO_2
- solid sorption process	X		(X)	?	fuel and process CO_2
Hybrid Systems					
- solar cement plant	X			"Yes but" (new kilns)	only fuel CO_2
- carbonate looping (cement / power plant)	X			yes (one-field application)	fuel and process CO_2

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Potential future application of CCS in the cement industry

- Short-term: no relevance due to

  - very high costs (> 50 $/t CO_2 avoided)

  - not existing availability of capture technologies

- Medium-term: depends on policy decisions and technical developments

  - climate policy (incl. USA, China, India)

  - cost reductions due to technical developments (target value: 20-30 $/t CO_2)

- Long-term: high relevance possible if

  - other options are exhausted

  - worldwide comparable costs for cement production would be introduced

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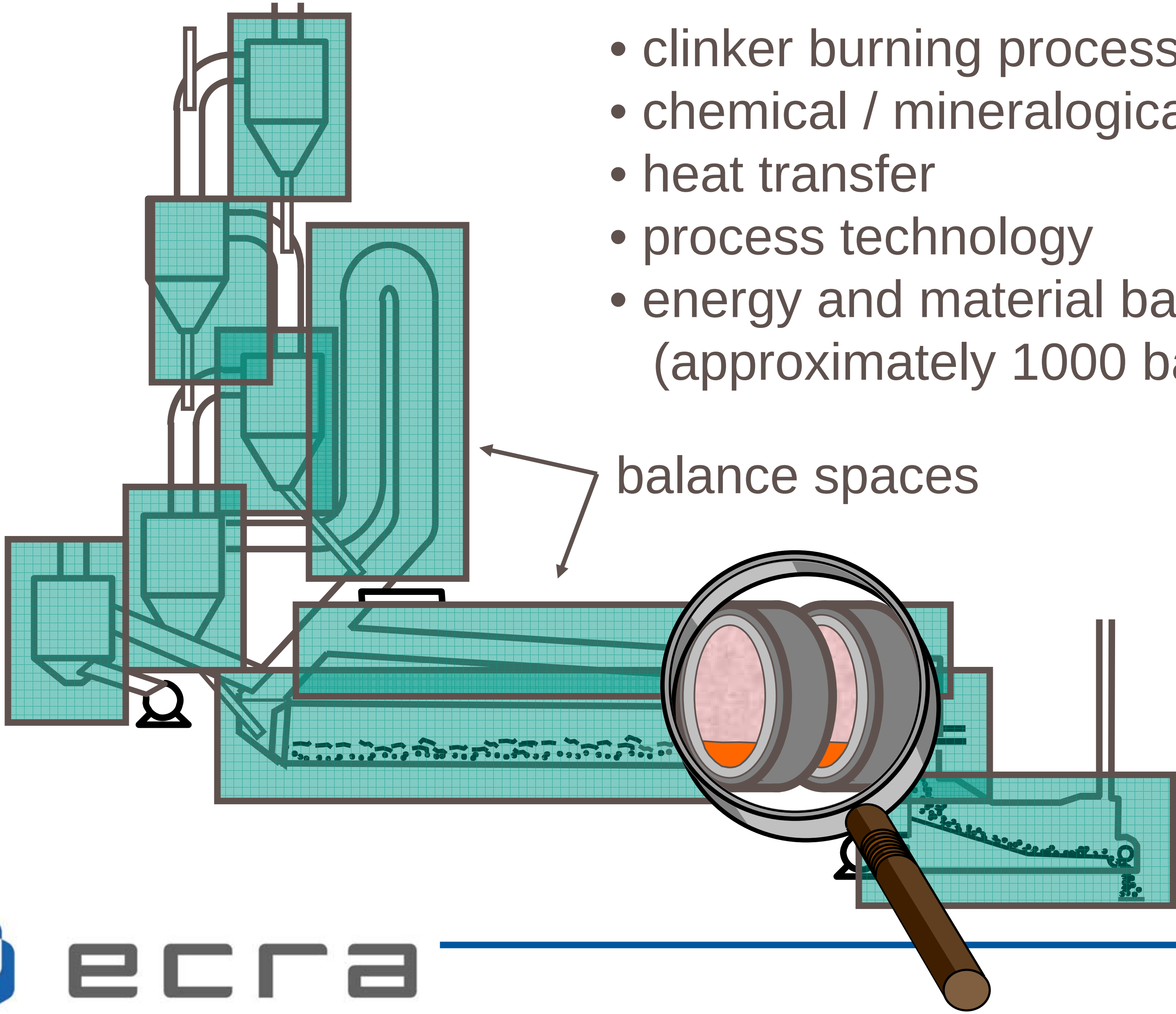
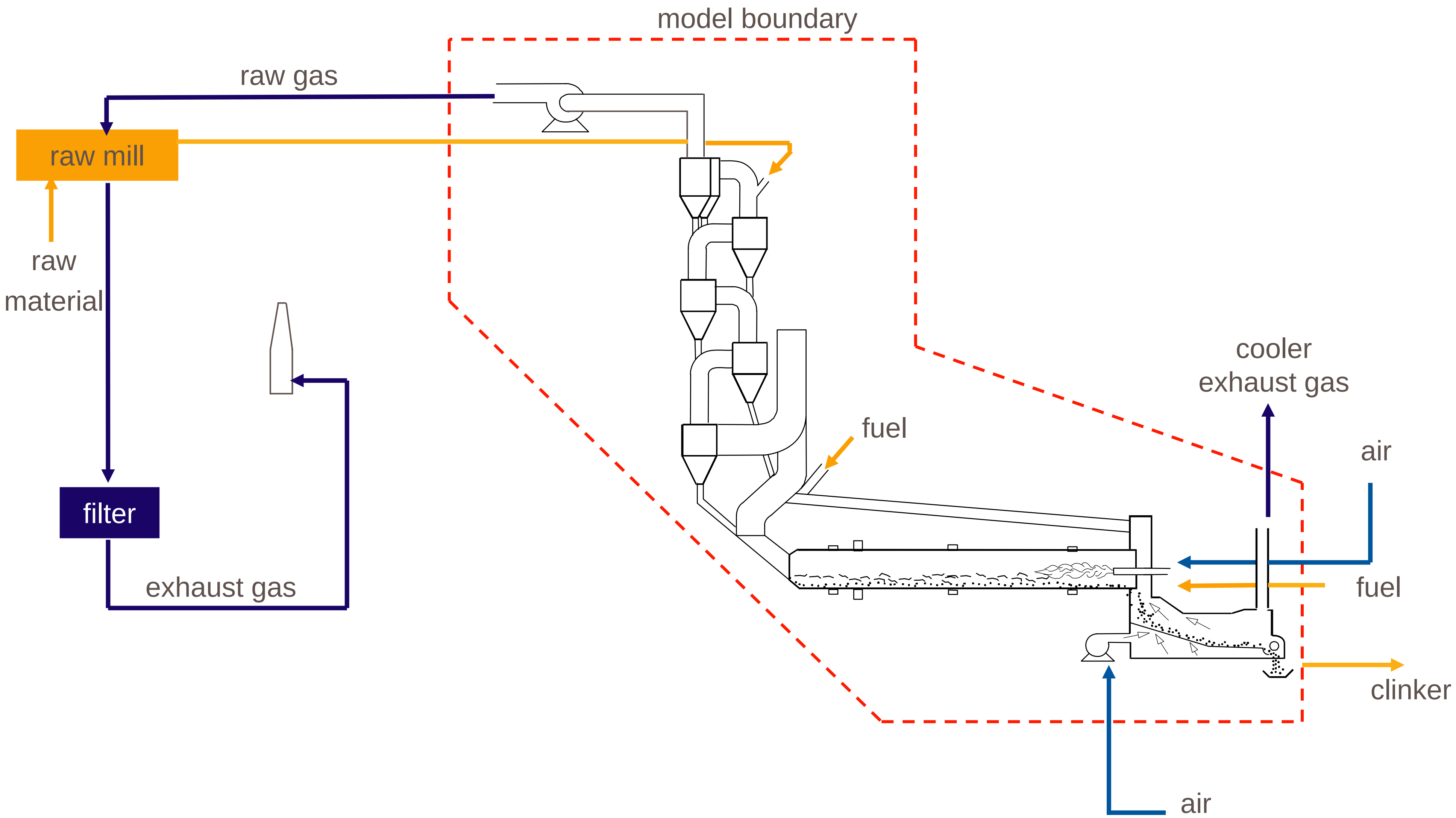
Modeling of the clinker burning process



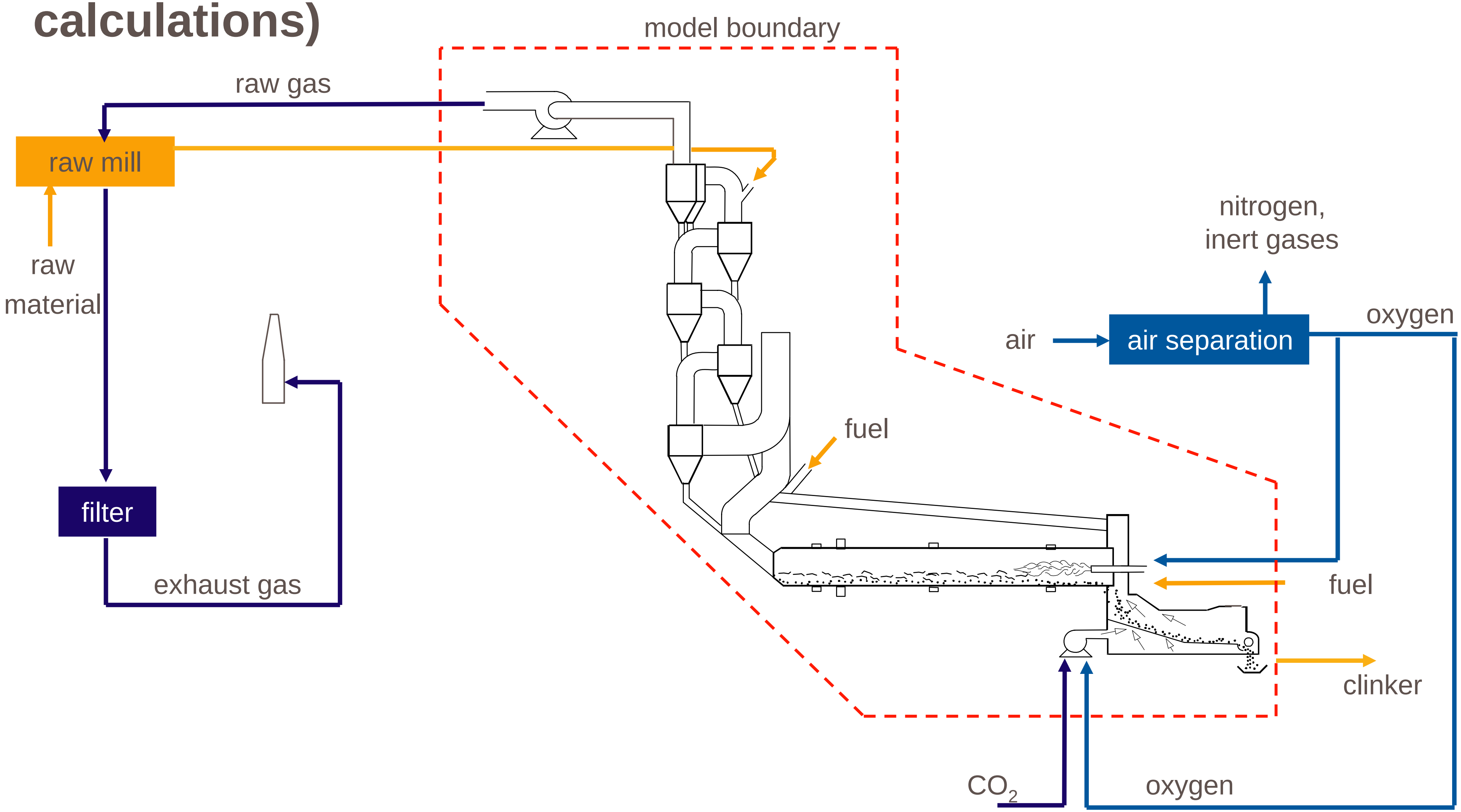
- clinker burning process (dry)
- chemical / mineralogical reactions
- heat transfer
- process technology
- energy and material balances
  (approximately 1000 balance spaces)

balance spaces

Schematic diagram of the clinker burning process (reference)



Schematic diagram of the clinker burning process with oxyfuel operation (based upon assumptions for the simulation calculations)



Summary and outlook

- CO_2 capture technologies are not technically available for the cement industry
- Pre-combustion technologies are not promising because only fuel CO_2 would be captured
- Oxy-fuel technology is state-of-the-art in a few other industry sectors and seems to be promising for new kilns
- Post-combustion technologies are state-of-the-art in other industry sectors, but on relatively small scale
- From a today's point of view CCS is by far too expensive for the cement industry
- Huge research efforts would be/are necessary to develop CO_2 capture technologies for the cement production process

Ecra research project shall enable the cement industry to give scientifically based reliable answers to political requirements in the future