

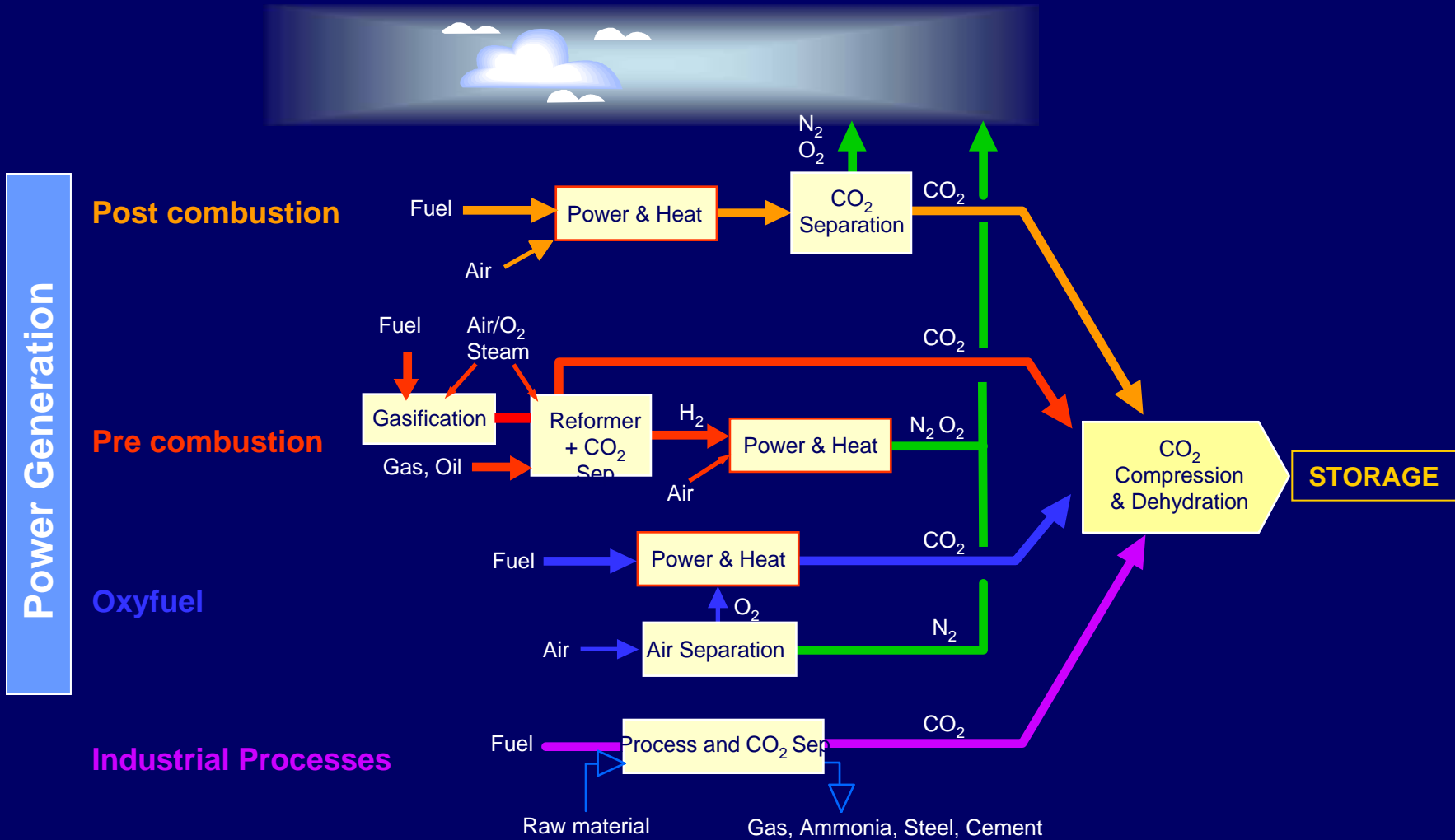
Calcium Sorbent Cycling for Simultaneous CO₂ Capture and Clinker Production



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- Fundamentals of carbonate looping cycles. The synergy between power and clinker production.
- Precalcination of CaCO₃ with “hot” CaO in a cement plant.

The main CO₂ capture systems



Intrinsic benefit of CCS applied to the cement industry

Avoided cost:

$$\$/t \text{ CO}_2 \text{ avoided} = \frac{\text{COST/unitofProduct}_{\text{capture}} - \text{COST/unitofProduct}_{\text{reference}}}{t \text{ CO}_2/\text{UnitofProduct}_{\text{reference}} - t \text{ CO}_2/\text{UnitofProduct}_{\text{capture}}}$$



It is usually “cheaper” to avoid CO₂ in processes with high specific emissions (like cement manufacture) than in processes of low specific emissions

Carbonator
T=600-700C

Flue gas
→

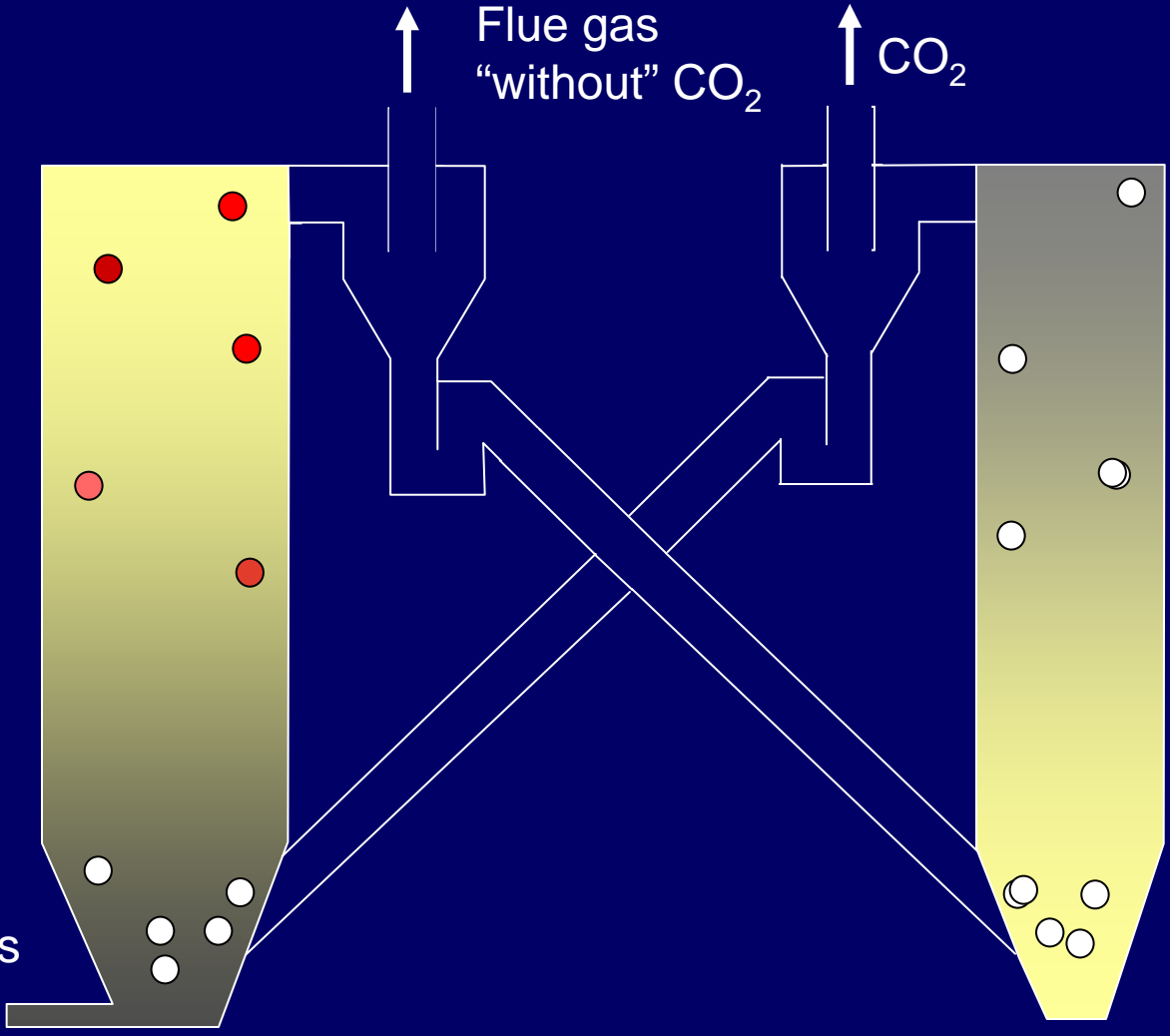
↑ Flue gas
"without" CO₂

↑ CO₂

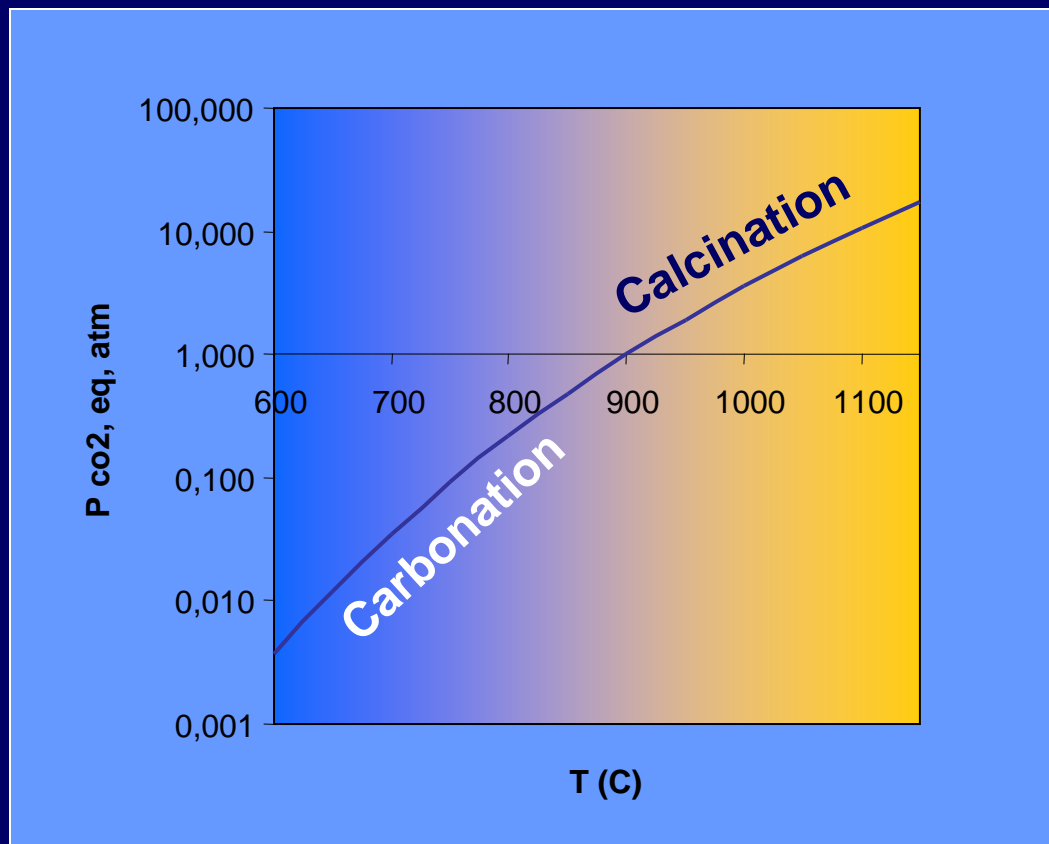
Calciner
T>870 C

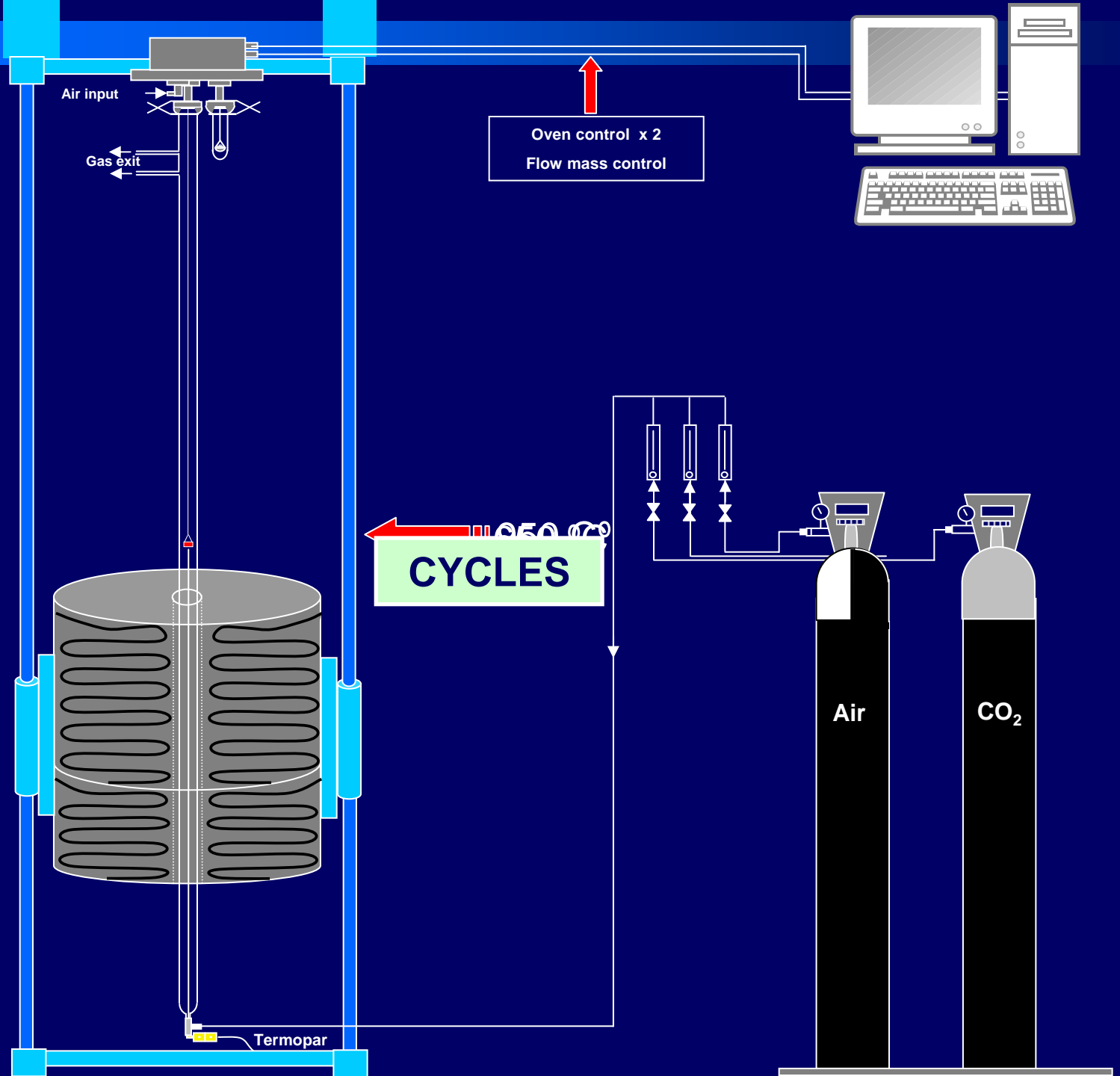
← Heat

- CaO
- CaCO₃

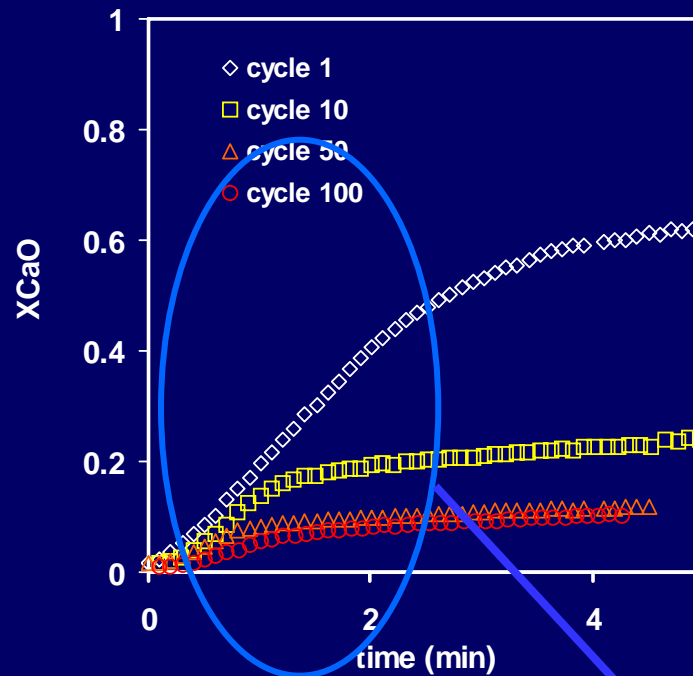


The equilibrium of CO₂ on CaO



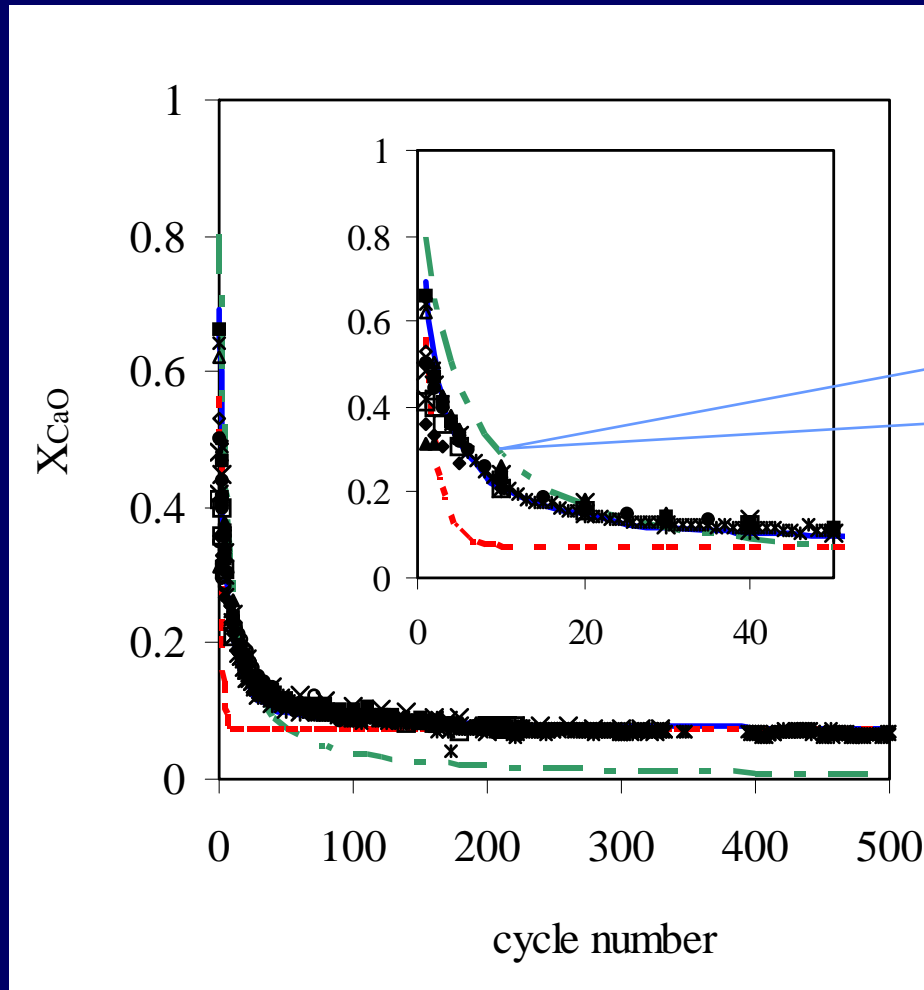


Reactivity drops at increasing number of carbonation calcination cycles



Reactivity is strong function of cycle number, temperature, CO₂ partial pressure, particle size, impurities, sulphur content, texture of CaO etc.

Sorbent deactivation curves for high number of cycles

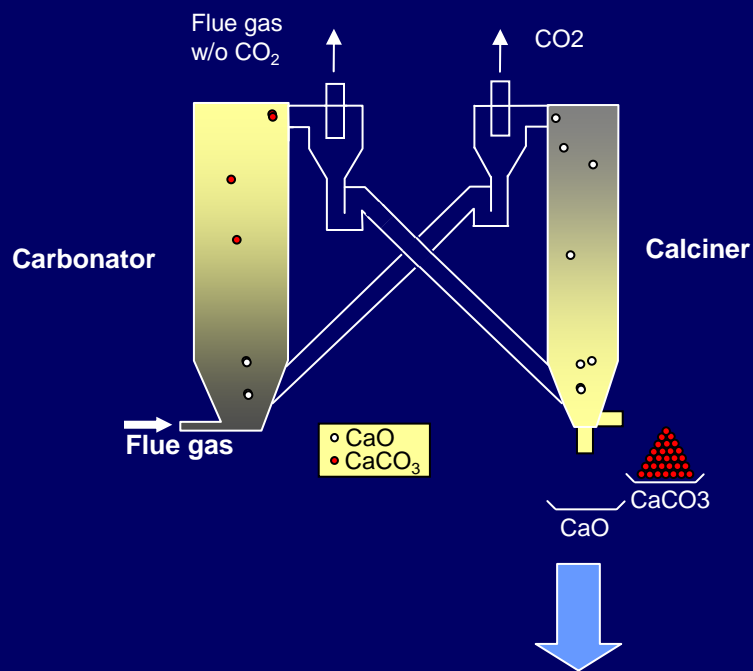
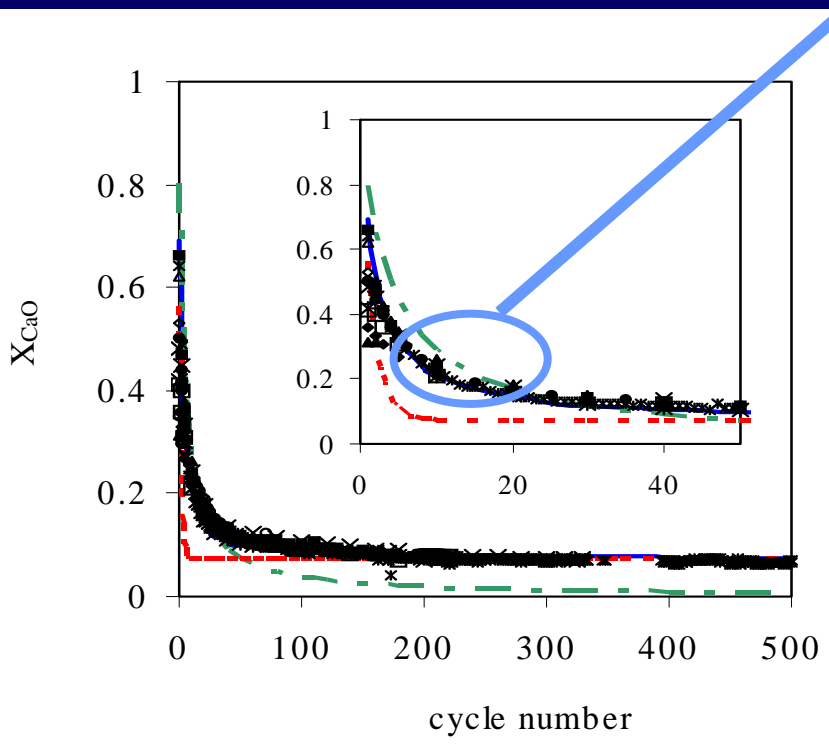


Decay in activity is only a function of cycle number and SO_2 content

(at $T < 950^\circ C$)

Residual activity

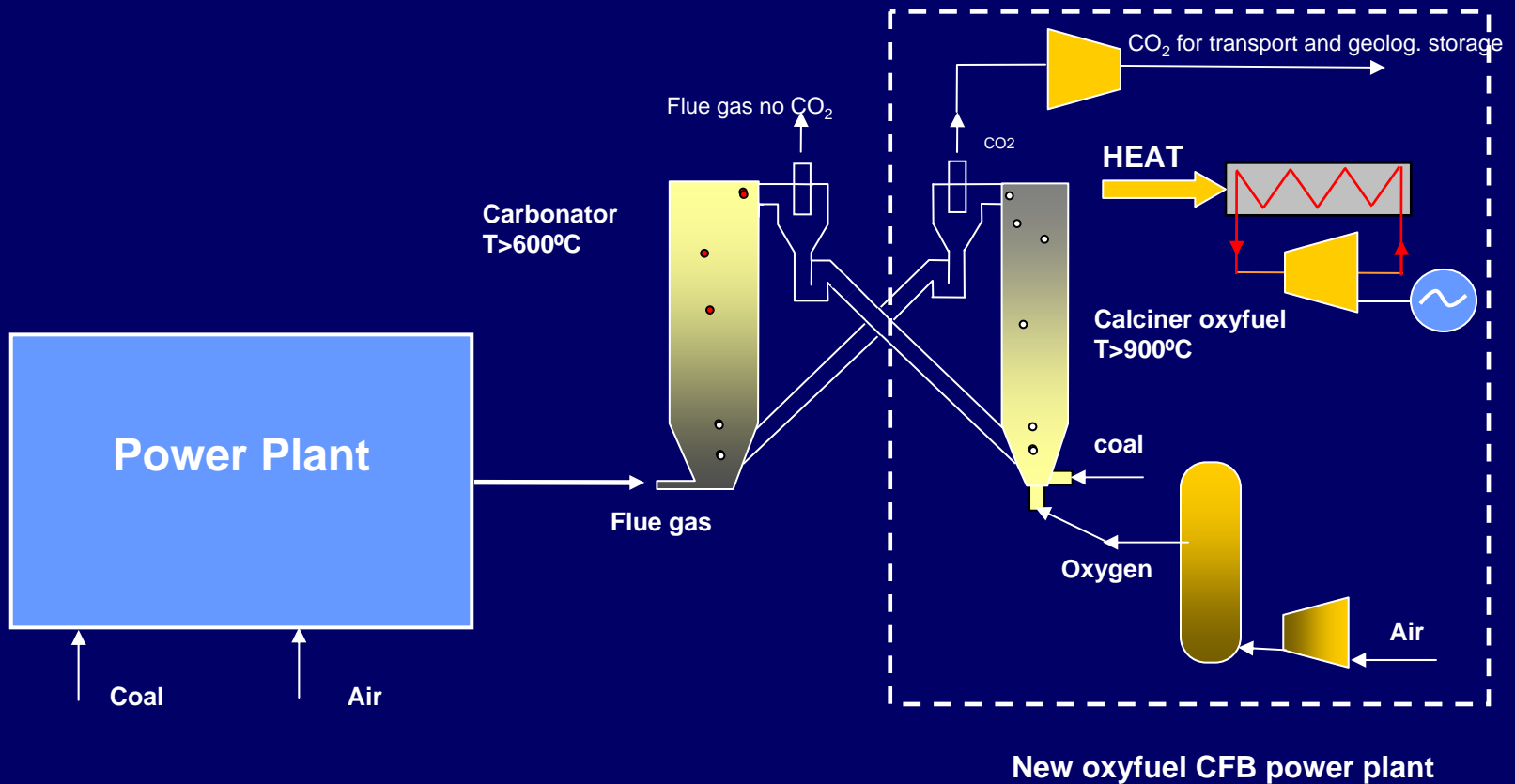
We can work with high make up flows to ensure a large presence these type of particles



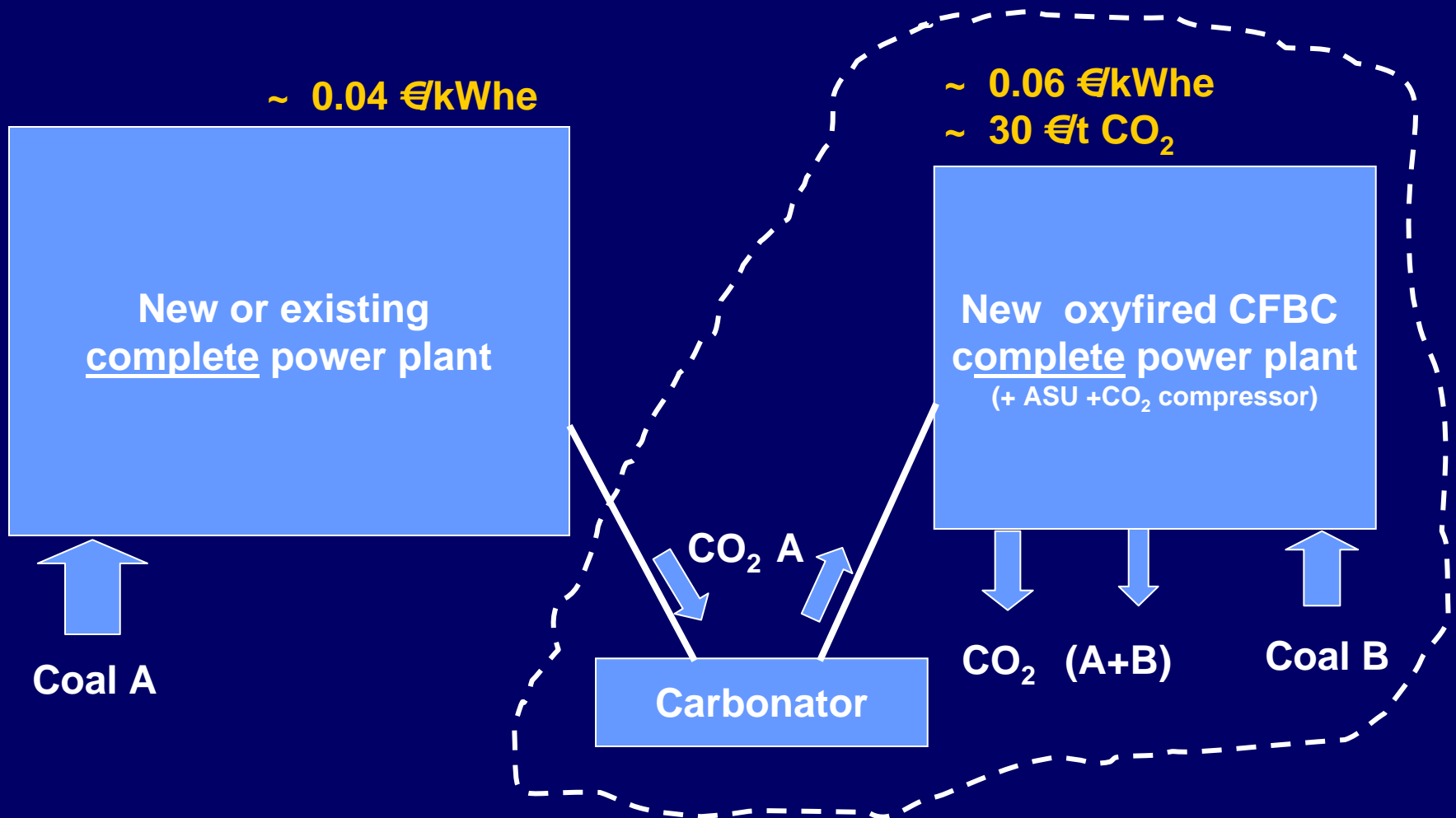
Suitable raw feed to a clinker oven

Application to existing power plants

Postcombustion looping



Cost structure of the full capture system

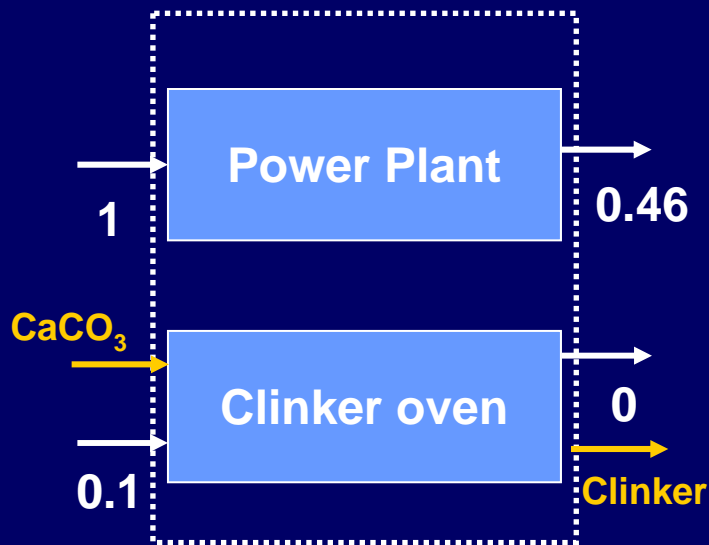


Cost of electricity can be around 0.05 €/kWh

Avoidance cost of CO₂ even below 15 €/tCO_2 (extra CO₂ captured as CaCO₃)

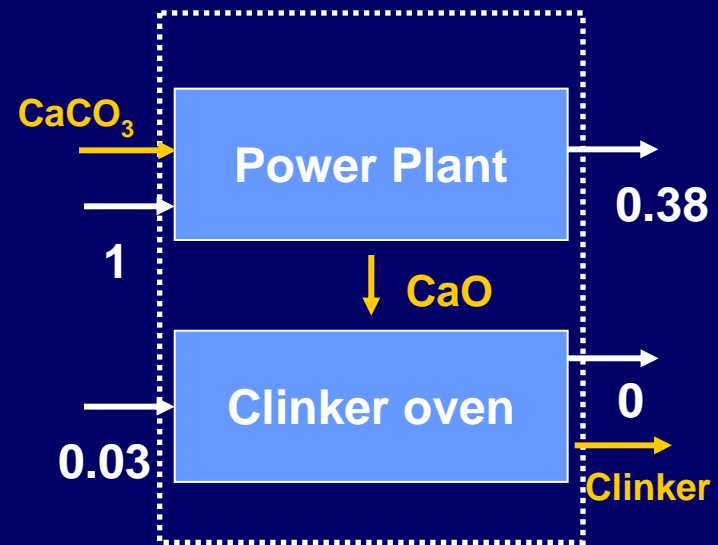
Synergies with a cement plant

Without carbonate looping



$$\eta_{\text{pow}} = 0.46 / (1 + 0.1) = \mathbf{0.42}$$

With carbonate looping



$$\eta_{\text{pow}} = 0.377 / (1 + 0.03) = \mathbf{0.37}$$

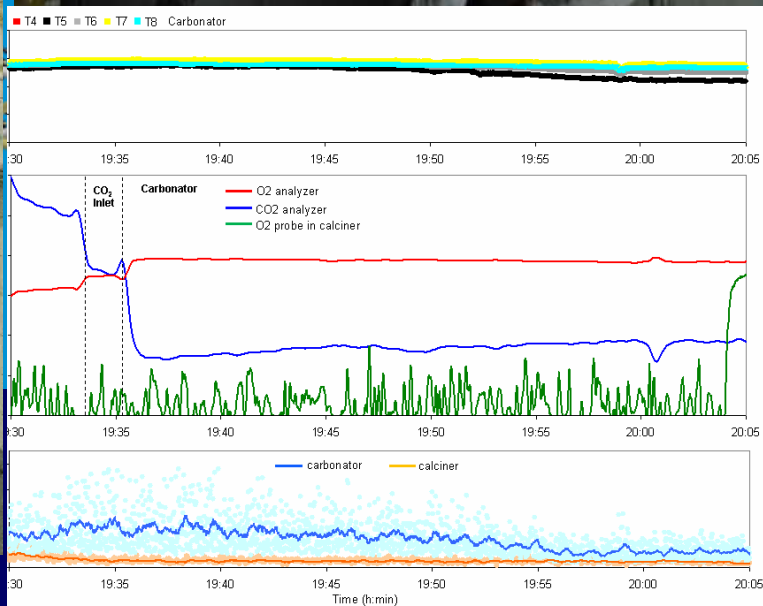
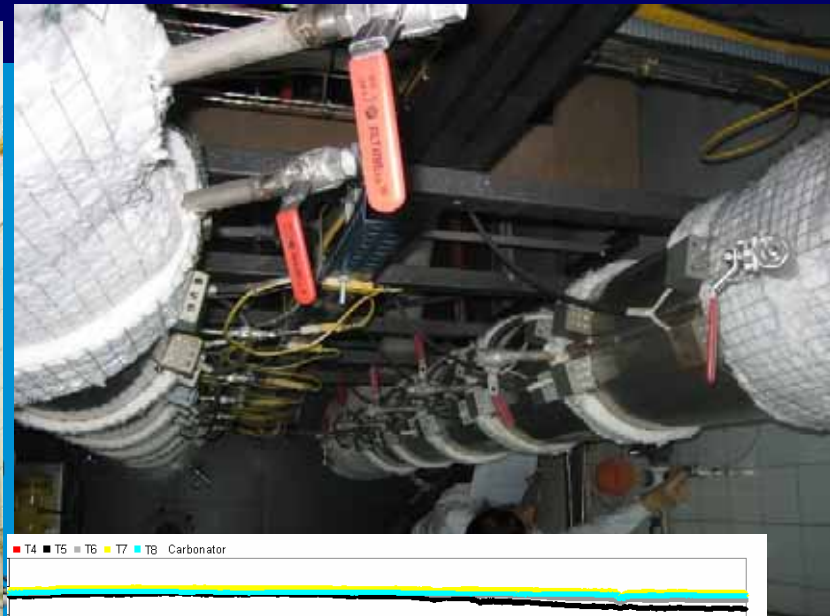
5 net points of ef. penalty
including compression to 100 bar

Summary of Potential Benefits

Potential for low
capture costs AND very
low efficiency penalties

- The capture step generates additional power
- Efficiency penalties intrinsically low
- Cheap and widely available CO₂ sorbent
- Several options are suitable for retrofitting
- It can be integrated with O₂ combustion
- **It can/should be integrated with a cement production plant**
- It can be applied to any fuel

30 kW interconnected fluidized bed carbonate looping system. (operating from 2007 at INCAR-CSIC)



Acknowledgements

(funding projects)

- European Commission C3-Capture (2006-2008), ISCC (2004-2006) del VI PM, CCCC (2003-2005) AdvHX (1999-2002) de CECA.
- CENIT-CO₂ (ENDESA-coordinator); module 3 (contract-U Fenosa/CSIC)
- Contract Hunosa/CSIC for the pre-design of a 1Mwt advanced test facility for CaO looping cycles.

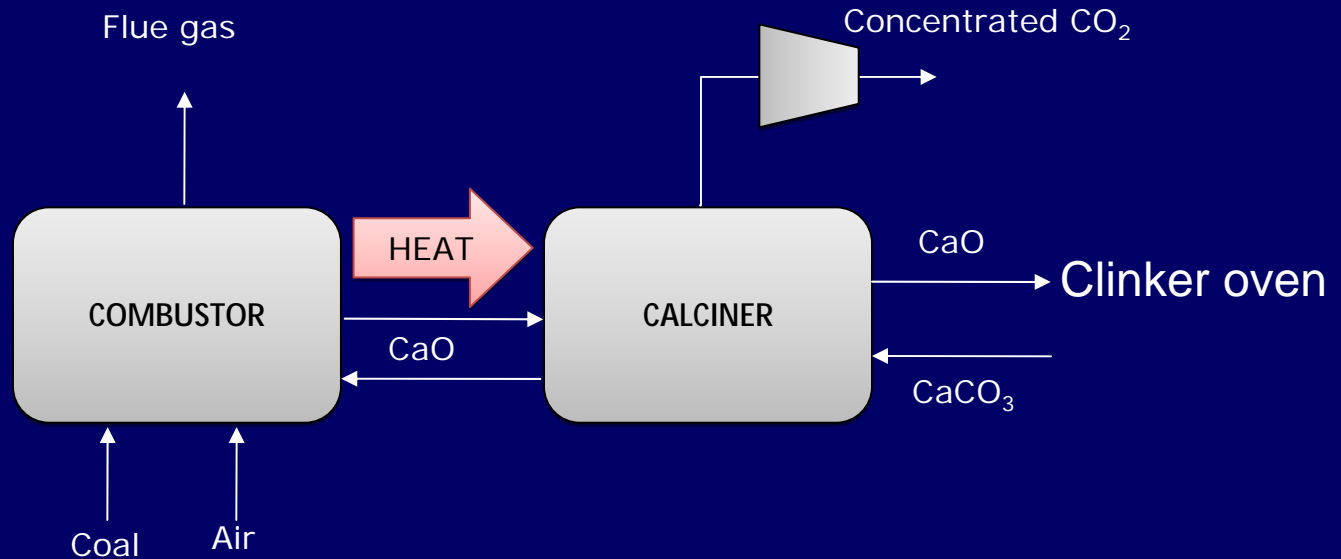
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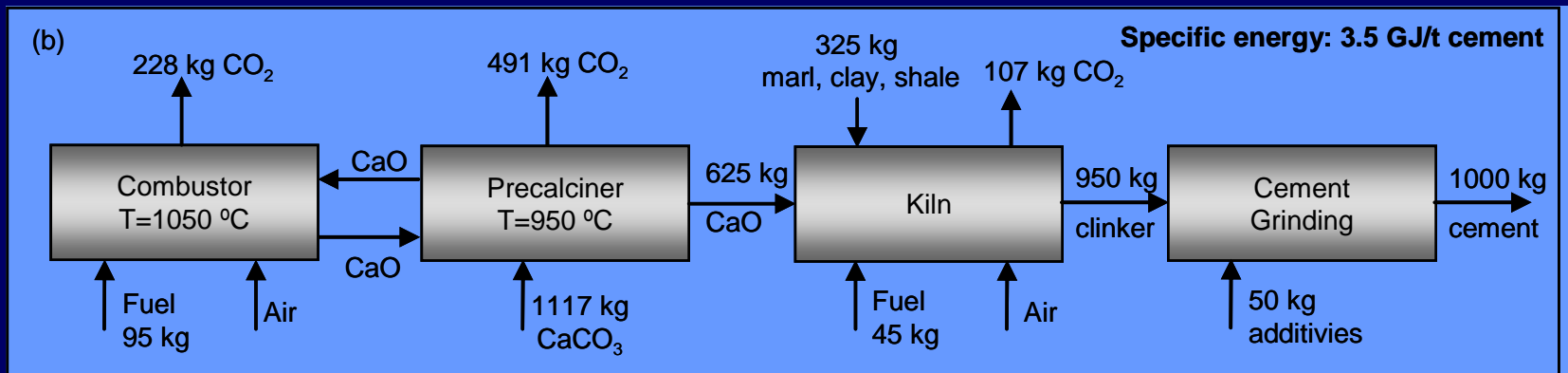
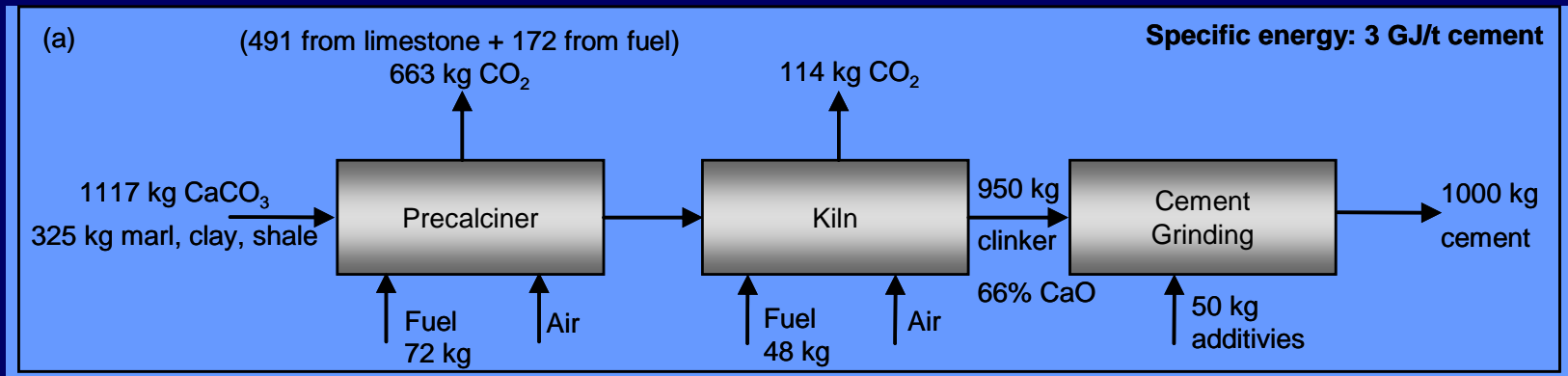
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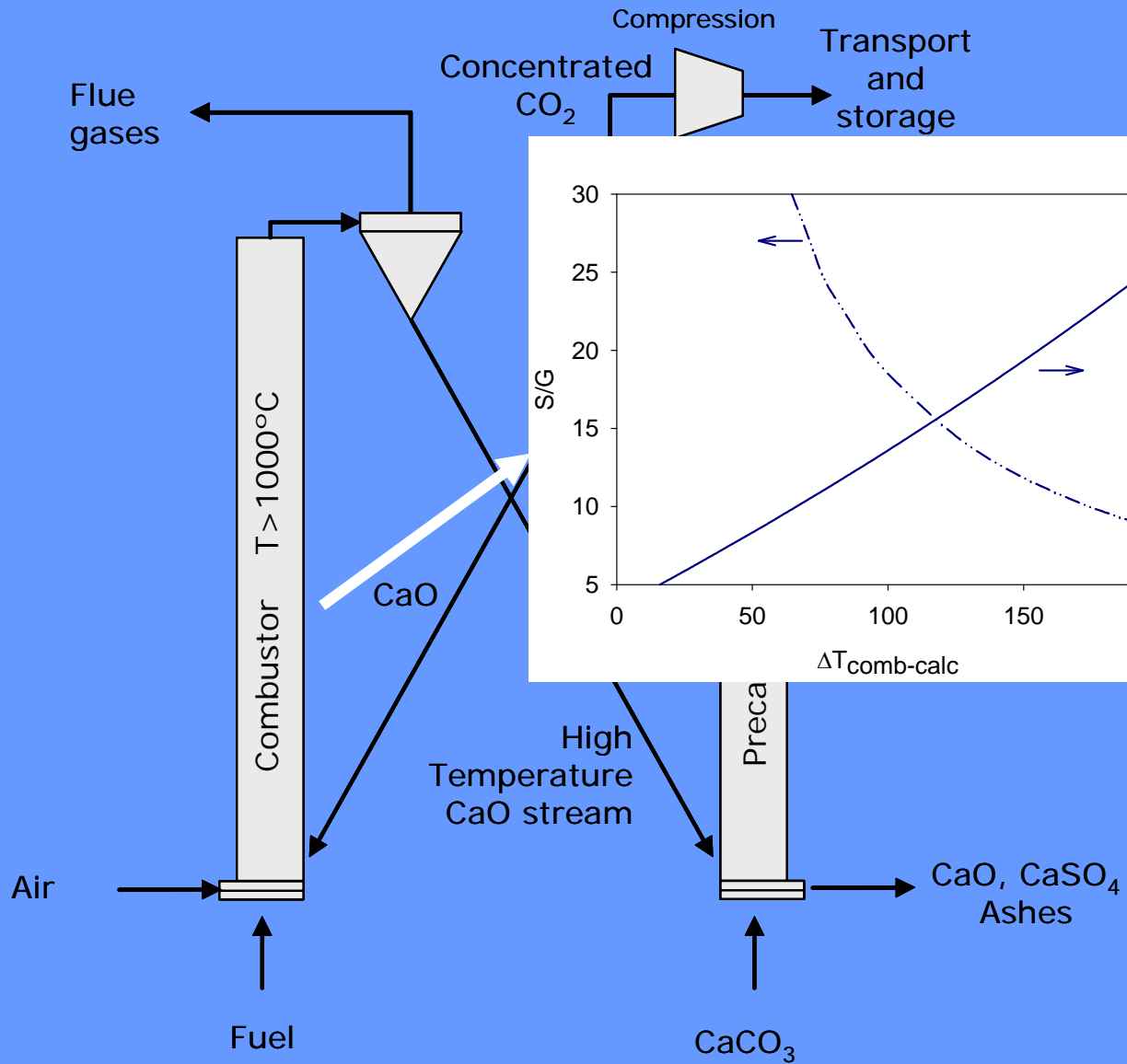
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Calcination of CaCO_3 with high T CaO



M&H balances. Existing vs proposed cement plant



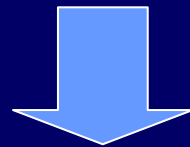


Previous publications

- The maximum capture efficiency of CO₂ using a carbonation/calcination cycle of CaO/CaCO₃. J C Abanades. Chem. Eng. J., 90, 303-306 (2002)
- Novel combustion cycles incorporating capture of CO₂ with CaO; J C Abanades, John E. Oakey; Diego Alvarez; Jouni Hämäläinen, 6th Greenhouse Gas Control Technologies, Kyoto-Japan, October 2002
- Conversion limits in the reaction of CO₂ with lime; J C Abanades, D. Alvarez. Energy and Fuels, Vol 17, 2, 2003, 308-315
- Progress of Sulfation in Highly Sulfated Particles of Lime; J C. Abanades, E. J. Anthony, F.García-Labiano, L. Jia, Ind. Eng. Chem. Res. 2003, 42, 1840-1844
- In-situ capture of CO₂ in a fluidized bed combustor. J.C. Abanades, E.J. Anthony, D Alvarez, D. Lu. 17th Int. Conf. on Fluidized Bed Combustion, FL-USA, ASME. May 2003. paper10
- A simulation study for fluidized bed combustion of petroleum coke with CO₂ capture. J. Wang, E.J. Anthony, J.C. Abanades 17th Int. Conf. on Fluidized Bed Combustion, FL-USA, ASME. May 2003, paper 169.
- Novel CO₂ control method by means of CO₂ chemical looping. C. Salvador, D. Lu, E. J. Anthony and J. C. Abanades. 7th International Conference on Energy for a Clean Environment. 7-10 July Lisbon 2003.
- Clean and Efficient Use of Petroleum Coke for Combustion and Power Generation. J. Wang, E. J. Anthony, J.C. Abanades. Fuel 83 (2004) 1341–1348
- Enhancement of CaO for CO₂ capture in FBC environment. C. Salvador, D. Lu, E.J. Anthony, J.C. Abanades. Chem. Eng. J. 2003, 96 (1-3) , 187-195.
- Capture of CO₂ from Combustion Gases in a Fluidized Bed of CaO. J.C. Abanades , E. J. Anthony, D. Alvarez, D. Y. Lu, C.Salvador. AIChE J 2004 , Vol 50, No. 7, 1614-1622
- Investigation of the solid flow between two fluidised beds connected by an orifice. G. Grasa, J. C. Abanades, J. Oakey. Chem. Engng. Sci. 59 (2004) 5869 – 5872
- Sorbent cost and performance in CO₂ capture systems. Juan C. Abanades, Edward S. Rubin, Edward J. Anthony. Ind. Eng. Chem. Res. 2004, (43) 3462-3466
- Fluidized bed combustion systems integrating CO₂ capture with CaO. J.C. Abanades, E. J. Anthony, J. Wang, J. E. Oakey. Env. Sci. & Tech. 39, 2861-2866 (2005)
- Pore size and shape effect on the recarbonation performance of calcium oxide submitted to repeated calcination/recarbonation cycles. D. Alvarez, JC Abanades, Energy and Fuels 19, 270-278 (2005)
- Determination of the critical product layer thickness in the reaction of CaO with CO₂. D. Alvarez, JC Abanades, Ind. Eng. Chem. Res 2005, 44, 5608
- Novel capture processes LI. Eide, M. Anheden, A. Lyngfelt, J. C. Abanades, M. Younes, D. Clodic, A. Bill, PHM. Feron Oil & Gas Science and Technology 60(3), 497-508 (2005)
- Process Optimization in Postcombustion CO₂-Capture by means of Repowering and Reversible Carbonation/ Calcination Cycle; Luis M. Romeo, Juan C. Abanades, Juan C. Ballesteros, Antonio Valero, Jesús M. Escosa, Antonio Giménez, Cristóbal Cortés, Jara Paño; 8th International Congress on Greenhouse Gas Control Technologies- GHGT-8, Norway 2006
- The kinetics of carbonation of CaO particles cycling in a CO₂ capture loop; G. Grasa, J.C. Abanades 8th International Congress on Greenhouse Gas Control Technologies- GHGT-8, Norway 2006
- CO₂ capture capacity of CaO in long series of carbonation/calcination cycles; G. Grasa, J.C. Abanades, Ind. Eng. Chem. Res. 45, 8846
- Economics of CO₂ Capture Using the Calcium Cycle with a Pressurized Fluidized Bed Combustor ; A. MacKenzie, D. L. Granatstein, E. J. Anthony, and J. C. Abanades Energy & Fuels 21, 2007
- The cost structure of a postcombustion CO₂ capture system using CaO; Abanades, J.C.; Grasa, G.; Alonso, M.; Rodríguez, M.; Anthony, E.J. Environmental Science and Technology 41(15), 5523, 2007
- Comparison of CaO-Based Synthetic CO₂ Sorbents under Realistic Calcination Conditions ; Grasa, G.S.; González, B.; Alonso, M.; Abanades, J.C. Energy and Fuels, 2007, doi: 10.1021/ef0701687
- Heat requirements of a CaCO₃ calciner when integrated in a CO₂ capture system.; Rodríguez, N.; Alonso, M.; Grasa, G.; Abanades, J.C. ; Chemical Engineering Journal In press doi:10.1016/j.cej.2007.06.005)
- Reactivity of highly cycled particles of CaO in a carbonation/calcination loop ; Grasa, G.S.; Abanades, J.C.; Alonso, M.; González, B. Chemical Engineering Journal, in press: doi:10.1016/j.cej.2007.05.017Páginas,
- Oxyfuel carbonation/calcination cycle for low cost CO₂ capture in existing power plants; Luis M. Romeo, J. Carlos Abanades, Jesús M. Escosa, Jara Paño; Energy Conversion and Management, 2008 (in press)
- Sulphation of CaO particles in a carbonation/calcination loop to Capture CO₂; Grasa G.; Alonso, M.; Abanades, J.C. Ind. Eng. Chem. Res., 2008 (in press)

Conclusions

- Carbonate looping cycles are a one of the most promising concepts to capture CO₂ from a power plant
- They can operate using cheap, natural limestones, but a large make up flow (and purge of CaO) is required
- Early opportunities for application of carbonate looping at large scale will require oxycombustion calcination and synergy with a cement plant.
- There is potential for even lower cost and high efficiency CaO looping concepts (no Oxycombustion required). In particular for CaCO₃ precalcination.



**There is an increasing interest worldwide
for carbonate looping R&D**