european cement research academy

Carbon Capture Technology
ECRA's approach towards CCS

Communication Bulletin

18 December 2009

ECRA – European Cement Research Academy

Contents:

1 ECRA's approach towards CCS

Due to the long term growth of the global economy and the development in many markets of the world, the demand for cement and concrete construction materials will continue to increase significantly. Within this context, the technical potential to reduce overall CO_2 emissions from cement manufacturing with today's technology is limited and certainly less than what abatement strategies currently being discussed demand and what stakeholders expect. The capture of carbon dioxide and its geological storage, often referred to as "carbon capture and storage" (CCS) is seen today as an emerging technology capable of reducing CO_2 emissions significantly. Many aspects of this technology, however, still remain open.

According to different abatement scenarios and the International Energy Agency's recently published Roadmap, the cement industry is expected to contribute to CO_2 mitigation globally by a set of different measures among which CCS plays a key role. After 2020, a commercial application of CCS technologies is anticipated to be available at least in the OECD countries, but to a significant extent also in emerging countries like China and India. It is obvious that any pilot or even demonstration plant can only be initiated on the basis of sound facts and figures on the technical and economical feasibility.

Against this background ECRA, the European Cement Research Academy, has decided to look at the capture of carbon dioxide as a prerequisite for a safe geological storage of CO_2. ECRA's goal is to examine the technical and economical feasibility of this technology as a potential application in the cement industry. ECRA lays strong emphasis on the global perspective of its research and also its sustainability aspect. This implies that not only CO_2 emissions as such, but also the huge energy demand for operating CCS plants will be taken into account.

ECRA's CCS research will focus on the capture process only. The transport and storage of CO_2 is seen as a technology to be used by other industries as well, and which as a consequence needs a much broader focus in addition to a political framework which still needs to be worked out. ECRA anticipates that governments and policymakers will join forces and will strive for sound storage technologies supported by good public acceptance.

In its project ECRA will concentrate on finding facts by giving information on the technical and economical feasibility of CCS. However, CCS is certainly a technology which – due to the expected cost - might have a strong impact on the cement industry as such. ECRA will therefore at all times communicate the current state of the project via institutions such as CSI, CEMBUREAU or PCA in order to allow the cement industry to anticipate future developments and be in a position to discuss potential impacts with its stakeholders.

In its CCS project ECRA has set up the structure for a long-term project which comprises five phases. Each of the phases requires the deliverables of the previous phase. Whenever a new phase is started, it has to be initiated by ECRA's Technical Advisory Board based on the input from ECRA's members. The phases of ECRA's CCS project are as follows:

Phase I: Literature and scoping study (January - June 2007) - finalized
Phase II: Study about technical and financial aspects of CCS projects, concentrating on oxy-fuel and post-combustion technology (summer 2007 – summer 2009) - finalised
Phase III: Laboratory-scale / small-scale research activities (autumn 2009 – summer / autumn 2011)
Phase IV: Pilot-scale research activities (time-frame: 2-3 years)
Phase V: Demonstration plant (time-frame: 3-5 years)

2 Project outline

Phase I of the project was finalised in spring 2007 and provided a first overview of CCS and its potential implications which can be foreseen for the cement industry. It includes an evaluation of the pros and cons of potential application in the cement industry. In the end, four options to capture CO_2 were looked at, which are currently being discussed: pre-combustion, post-combustion, oxy-fuel technology and carbonate looping. Although a detailed technical understanding of CCS is still pending, the study concluded that all capture technologies are today far from being applicable to the cement industry due to technical and cost reasons. Nevertheless, some capture technologies seem to be more appropriate for the potential application at cement kilns than others. This applies to oxy-fuel and post-combustion (chemical absorption) technologies. Consequently the ECRA Technical Advisory Board decided to continue the project and launch phase II in order to look at these technologies in a feasibility study in more detail. The report summarising the results of Phase I is available on **www.ecra-online.org**.

Phase II started at the end of 2007 and was completed in summer 2009. The main objective in this phase was to perform a more detailed study for CO_2 capture at the clinker burning process which focused on oxy-fuel and post-combustion measures (chemical absorption). The budget for phase II was supplied by the ECRA members and industrial project partners such as technology manufacturers and gas suppliers. The report on phase II can also be downloaded from the ECRA website (see **www.ecra-online.org**).

In October 2009, following the completion of phase II, the Technical Advisory Board decided to continue the ECRA CCS project and carry out phase III. According to the project schedule, phase III shall last from autumn 2009 until summer/autumn 2011. The main research tasks would be running laboratory-scale tests with different absorbents with typical cement kiln exhaust gas mixtures, extended process modelling, the development of more detailed plant layouts, and the modification of process technology. In this project phase, universities, research organisations and specialists from cement and equipment companies will cooperate. ECRA members, industrial partners and also CSI and CEMBUREAU have been invited to contribute to the budget of phase III.

The following project phases (phase IV and V) are still to be decided upon. They could foresee pilot-scale trials to gain real-case experiences. These pilot tests should demonstrate the reliability and effectiveness of capture processes. From today's perspective, this project phase could be started - if at all - not before the end of 2011 and should last 2 or 3 years. The execution of the associated work packages would require cooperation with leading

equipment suppliers or rather major licensors of capture technologies. Phase V is even more subject to the final decisions of the ECRA members, funding opportunities and the political and technical framework for CO_2 storage. However, with its various stages of the CCS project, ECRA will examine the technical and economical feasibility of CCS as a CO_2 abatement option for the cement industry.

3 Research objectives and proposed budget for Phase III

The first phases of the ECRA CCS project have shown that oxy-fuel and post-combustion (chemical absorption) are the most promising technologies for CO_2 capture in the cement industry. In the framework of phase III, more detailed studies and experimental investigations shall be carried out to prepare the ground for first pilot-scale trials in the cement industry.

The relevant work packages regarding oxy-fuel combustion and post-combustion are specified below.

3.1 Oxy-fuel technology

The application of the oxy-fuel technology with flue gas recirculation for CO_2 emission reduction was predominantly investigated by the energy sector during the last years. The first pilot plants with oxy-combustion have been started and demonstration plants are already planned in this sector by 2015. However, the transferability of these results to the cement industry is limited due to the different requirements in plant operation and the impacts on product quality. The cement industry so far only has experiences with oxygen enrichment to increase production capacity. Within phase II, first basic findings about the impact of the oxy-fuel operation on kiln operation and chemical-mineralogical product reactions were derived from process modeling and laboratory tests. A process design has been developed including issues such as waste heat recovery, oxygen supply and flue gas conditioning. There are still some technical issues that have to be solved in the following phase III.

A1: Process modelling

In the first step, wet and dry flue gas recirculation will be compared, the optimal method can thus be determined. Furthermore the partial oxy-fuel process (only calciner in oxy-fuel operation) should be implemented in the model. Taking all basic research results gained (temperature shift, material reactions etc.) into account, an optimum operation point (recirculation rate, O_2 concentration, kiln geometry etc.) should be identified by a further comprehensive simulation study. The aspired research results should be an optimum specification of the operational mode and design of the kiln plant.

A2: Burner design

The burner design plays an important role in the considerations that have to be made for the further steps of developing an oxy-fuel cement plant. In the current modelling, the primary “air” consists of nearly pure oxygen. The gas flow was therefore reduced to keep the O_2 flow constant. It is not yet proven whether this amount of gas suffices to form a stable flame and transport the fuel. Otherwise it has to be investigated whether a part of the recycled gas stream should be supplied additionally to the oxidizer and how much is necessary to avoid

instability of the flame. Moreover, the burner design can be affected by this and might be changed. Thus it is essential to investigate the requirements via CFD modelling and develop an adapted burner design for oxy-fuel operation. These investigations cannot be done by the Research Institute itself and require cooperation with external project partners.

A3: Further investigations on clinker quality

As was suggested, further investigations on the clinker quality should be made. The previous investigations (X-ray diffraction, microscopy) on the microstructure of the laboratory clinker showed no significant effect from the CO_2 atmosphere. Now the strength characteristic and the reactivity by measuring hydration heat should be proven to ensure a high grade of quality. Furthermore the impact of the CO_2 atmosphere on the properties of clinker with different reactivity shall be tested.

A4: Optimisation of the refractory

The refractory brickwork has to meet special requirements due to the changed burning conditions, like higher temperatures and influenced heat transfer, and further investigation work is necessary. It should be assessed whether the current refractory is sufficient or should be optimised. In this case a suitable solution should be developed. Relying on the gained simulation data in the first period of the project, the refractory investigations constitute an issue for the second part.

A5: General layout for flue gas conditioning

The power-intensive air separation and flue gas conditioning have a strong impact on operating costs. The results from phase II have shown an increase in operating costs of about 45 % compared to a conventionally operated cement plant. The energy demand for the flue gas conditioning depends strongly on the concentration of impurities. In any case appropriate gas cleaning has to be applied before compression of the flue gas. To enrich the CO_2 in the gas stream, the compression-liquefaction is the most economic solution from today's perspective. The disadvantage of the system is the CO_2-containing exhaust gas stream to the environment, which limits the possible capture rate. The final pressure of the CO_2, which depends on the transport distance, can be generated by a multi-stage compressor. As neither the detailed requirements on CO_2 purity for transport and storage nor the exact flue gas composition is known yet, this issue should be treated in the second part of the project phase. Hence an adequate layout for flue gas conditioning, including cleaning, purification and compression should be devised to meet the required impurity level. On the other hand, requirements on the level of non-condensables (N_2, O_2, Ar), which are mainly affected by the false air ingress, shall be elaborated to ensure a high capture rate.

A6: Detailed development of overall layout

Based on the simulation results, which will determine the requirements on kiln design, a detailed overall layout can be developed. A small working group composed of the Research Institute, equipment and gas suppliers as well as interested members form the cement industry should therefore be established. Issues such as the construction of the kiln plant including clinker cooler, calciner and sealings should be evaluated. This would allow a more detailed statement about the cost estimation beyond the one listed in the final report of phase II. On this basis, a concept for large-scale tests can be developed to validate the modelling

results. Operational and safety aspects, such as increasing coating formation, should therefore be elaborated.

A6.1: Optimisation of the sealings

Oxy-fuel technology requires further development with regard to sealing the kiln plant. In particular the connection between static and dynamic components, i.e. at the kiln inlet and hood, poses a challenge. This is essential to produce a flue gas with an adequate, high CO_2 concentration, in order to minimise flue gas cleaning effort.

A6.2: Two-stage clinker cooler

To avoid a CO_2-containing exhaust gas stream from the cooler, the cooler is separated gas-tight into two stages. Basically two-stage-coolers exist in white cement production, but have to be adapted to the oxy-fuel application.

After proving the functionality of oxy-fuel operation in cement plants by small-scale tests, the project can provide the pilot-scale status according to schedule from phase IV. From today's perspective this project phase - if at all - could not be started before the next 5 to 8 years.

3.2 Post-combustion technologies

At power plants, post-combustion CO_2 capture projects are operated in pilot-scale, at the moment. Many large-scale capture projects are currently planned and are supposed to provide an essential step towards commercialisation. It is expected that results from these projects will be transferable to the cement industry. Nevertheless, certain differences exist and require detailed examination for potential application in the cement industry.

B1: Simulation of amine-based absorption process

First of all, a process model of the CO_2 capture system will be added to the existing clinker burning simulation. Within a first work step, the rigorous chemical model is prepared that involves all relevant equilibrium and kinetic parameters. With this model, the optimal design of an absorption column could be estimated. Another important objective is the simulation of different chemical solvents to define strategies for further process improvement.

B2: Laboratory experiments on absorbent degradation

The basic process concept for post-combustion carbon capture in a cement plant will be similar to that of a power plant. However, as the flue gas composition shows slight differences, a detailed study of minor gas constituents and their impact on the applied chemical solvent is necessary. Using a small laboratory reactor, the impact of cement flue gas composition on the solvent stability is subject to the experiments.

Within the first step, the experiments will be conducted in the laboratory with gas mixtures based on the typical flue gases from cement plants. The results from parameter studies, including the most critical components like O_2, SO_2, NO_2 and trace elements are to be verified with field tests in different cement plants.

B3: Small-scale field trials

Based on the results from the prior tasks, it is intended to conduct first field studies with mobile small-scale carbon capture units. For this work package cooperation with a specialised partner is required. As a main objective, this package shall supply first operating experience to the cement industry including conclusions for further upscaling.

B4: Design of pilot/demonstration plant, call for FEED study

Based on results and conclusions from tasks 3.2.1 through 3.2.3, the implementation of post-combustion carbon capture as a retrofit measure to an existing cement plant will be designed. A FEED study (Front-End Engineering Design) will be an important step towards the application of post-combustion carbon capture in the cement industry. This task should be executed by a collaboration of the Research Institute and equipment suppliers. With results from the work at the Research Institute and the general development of CCS technology, the study shall enable profound decision making on the further application of post-combustion capture in the cement industry.

3.3 Project management

The project coordination is carried out by ECRA. It comprises the

- organisation of meetings of the Steering Committee
- cooperation with external project partners and coordination of their activities
- budget follow-up and reporting
- issuing of progress reports
- issuing of the final report on phase III

3.4 Proposed schedule

Work items																									Mon
	2010												2011												
	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	18
A: Oxyfuel Technology																									
A1: Process modelling																									17
A2: Burner design, CFD																									12
A3: Investigations on clinker quality																									6
A4: Optimisation of refractory lining																									6
A5: General layout of flue gas conditioning																									9
A6: Detailed development of general layout																									16
A6.1: Optmisation of sealings																									12
A6.2: Clinker cooler design																									12
B: Postcombustion Technology																									
B1: Simulation of CO_2 scrubbing process																									9
B2: Laboratory tests on amine degradation																									17
B3: Small-scale tests																									12
B4: Design of pilot/demo plant, FEED study																									6
C: Project coordination																									
C1: Coordination																									21
C2: Reports																									4

4 Project management

The research project is managed by ECRA. A Steering Committee will be responsible for conducting the project in detail. Consequently ECRA is also in charge of the financial administration of the project.

The Steering Committee will be comprised of representatives from ECRA member companies and the relevant equipment manufacturers which are involved in the ECRA project. In addition every partner has the right to nominate a representative for the Steering Committee.

The Steering Committee will set up a work plan to conduct phase III. This will include the installation of working groups if necessary or the nomination of experts to conduct certain sub-tasks. The Steering Committee also has the task of guiding the research project and making a proposal for the further proceedings to the ECRA Technical Advisory Board. Progress reports will be issued every 3 months and a final report issued at the end of phase III (end of 2011).

5 ECRA – The European Cement Research Academy

ECRA, the European Cement Research Academy, was founded in 2003 as a platform on which the cement industry stimulates, organises and undertakes research activities in the context of the production of cement and its application in concrete. By creating and disseminating knowledge from research, ECRA's aim is to facilitate and accelerate innovation to guide the cement industry in the 21st century.

ECRA's activities are pre-competitive and comprise seminars, workshops and also dedicated research projects initiated or organised by ECRA itself. The seminars and workshops provide a platform to communicate the latest research findings, while the research projects focus on issues which might not be tackled by a single company itself due to their more general importance for the industry.

Today, over 40 cement producers are members of ECRA. A Technical Advisory Board staffed with European members steers the Academy. The Board is responsible for defining the focus and the scope of the Academy's programme. It also monitors the Academy's financial position and its annual budget. Under the chairmanship of Daniel Gauthier, HeidelbergCement, representatives from major cement producers work on the Board.

ECRA is regarded as a research body with high competence in sustainable cement and concrete technology acting proactively for its member companies. Based on its work, ECRA accumulates a high level of expertise itself and within a network of competent institutes. In addition ECRA is able to act not only as a research platform but also as a consultant for other institutions or even customers from the cement industry.

ECRA understands itself as a part of a network which comprises various research facilities, such as universities, federal institutes or research centres of cement companies or equipment suppliers. In this context, ECRA is able to develop a knowledge centre which benefits from the best institutes in the respective research areas acting as a core competence centre.