PERIODIC ACTIVITY REPORT

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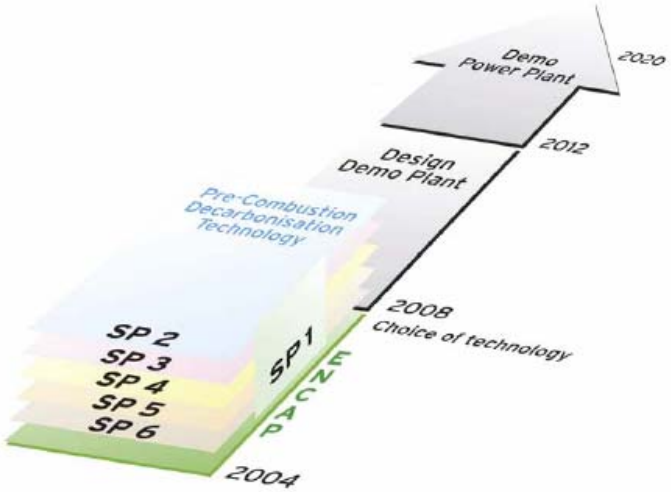
2004-03-01	5 years	Revision due to Y4 EC Review

ENCAP Integrated Project

Development and verification of pre-combustion technologies for CO2-capture in Large Scale Power Plants



PUBLISHABLE EXECUTIVE SUMMARY

Introduction - ENCAP objectives and structure

ENCAP is a five-year integrated project (IP) with in the EU sixth framework research programme. The project will run for five years and has a total budget of 22.2 MEUR. The EC contribution to the project is 10.7 MEUR. ENCAP started in March 2004.

The present report summarizes the activities and results during the fourth year of the project (2007-03-01 to 2008-02-29).

The technological objective of ENCAP is to cut lead-time and improve cost for emerging pre-combustion carbon capture technologies[1] attributed to power generation for continued use of fossil fuels in Europe - and the world - in a resource-efficient and environmentally benign manner.

The stated target of ENCAP is to provide pre-combustion capture technologies in power cycles operated by natural gas, hard coal and lignite with the objective of achieving:

1) at least 90% capture rate for CO_2
2) 50% capture cost reduction – from a level of 50-60 € per tonne of CO_2 captured.

The scientific objective is to generate new knowledge and comprehension of systems, processes, materials and matter by characteristics of potentiality, constraints and governing mechanisms pertaining to pre-combustion capture from fossil fuels, with a bearing on solutions that (might) facilitate sequestering of CO_2. This objective requires targeted fundamental and applied research, and topical involvement by leading European R&D institutions.

ENCAP delivers results that have the potential for commercial exploitation beyond year 2015 and will generate knowledge and results that enable power companies to launch design projects by 2008-2010 aimed at large-scale demonstration plants.

The RTD activities in ENCAP are structured in 6 sub-projects:

- SP1: Process and Power Systems
- SP2: Pre-Combustion Decarbonisation Technologies
- SP3: OxyFuel Boiler Technologies
- SP4: Chemical Looping Combustion
- SP5: High-Temperature Oxygen Generation for Power Cycles
- SP6: Novel Pre-Combustion Capture Concepts.

The ENCAP project is planned in two phases. Phase II was planned to start with a decision on a selection of technologies for large scale testing in the middle of the project time (beginning of 2007). The two-phase approach was base on the fact that it was not possible to decide which of four pre-combustion technologies under development in ENCAP should be most relevant for large scale testing in order to meet the overall objective for the ENCAP project of verification of the performance of a technique for a recommendation for a large scale demonstration power plant. The four technologies planned for large scale testing were OxyFuel, Chemical Looping, High-Temperature Oxygen production technologies and technologies found among the Novel Pre-Combustion capture concepts. The plan for SP2 – Pre-Combustion Decarbonisation Technologies - included already from the beginning the larger scale testing necessary to meet the set-up goal for

[1] P*re combustion* denotes decarbonisation by appropriate measures taken prior to (or during) combustion in contrast to *post-combustion* that addresses CO_2 removal from a flue gas (after combustion)

verification in the actual sub-project. During year 3, ENCAP has entered into Phase II. The preparation for a large scale testing decision started already during 2006 with six proposals to large scale testing. The project has decided to focus further discussions and planning on Large Scale Testing on the 30 MWth OxyFuel pilot under construction (investments outside the ENCAP budget) by Vattenfall at Schwarze Pumpe Power Plant site, Germany. Discussions with the some of the partners regarding work contribution during the testing, access to test results and financial contribution was discussed during year 3 and a preliminary plan for this has been developed. The contents of the test program to be performed and the necessary instrumentation of the plant have been discussed between some of the ENCAP SP3 partners. The final decision was planned to be taken in the autumn 2007. This was not achieved. The planning and preparation of the tests has continued during year 4, leading to a final decision during year 5 and that the actual Large Scale Test period is planned for in the very end of the ENCAP project. The overall research activity in the project has decreased during year 4. However research and development will continue in some of the SPs.

Overall conclusions drawn in SP1 have had a direct bearing on systems recommendations and the choice of pilot test as planned for Phase II of the project (started in August 2006). This means that the R&D issues on ENCAP that affect processes and systems - in SP2 through SP6 – have been consistently scrutinised in SP1.

Partners involved

The ENACP project gathers 31 European entities. The consortium consists of highly ranked RTD providers, leading European manufacturers and large energy providers, and creates an important European Research Area of CO_2 capture technologies.

The ENCAP partners are:

Vattenfall*	ALSTOM**	DLR	Chalmers
DONG Energy	Siemens	CERTH/ISFTA	NTNU
RWE Power	Doosan Babcock	TNO	Universität Paderborn
PPC	Linde	IFP	University of Stuttgart
StatoilHydro	Lurgi	SINTEF***	University of Twente
TOTAL****	BOC		University of Ulster
	Air Liquide		

*Participates with three legal entities within the Vattenfall Group

**Participates with five legal entities within the ALSTOM Group

***Participates with two legal entities within the SINTEF Group

**** Associated partner to the consortium

Work performed and main results achieved during the fourth year

Research Activities

In SP1 "**Process and Power Systems**", the following has been achieved during year 4:
The evaluation and benchmarking of CO_2 capture concepts and technologies from SP2 – SP6 has been updated. Compared to the corresponding reference cases, the net electric efficiencies are reduced with 6 – 9% points for the IGCC pre-combustion capture technologies and oxy-fuel PF and CFB technologies, and with around 15% points for the natural gas fired IRCC pre-combustion capture technology. The calculated electricity generation costs for those technologies increase around 30 – 60% compared to the reference cases, with resulting CO_2 avoidance costs of around

10 – 40 € per tonne CO_2 for the solid fuel based technologies and – mainly depending on natural gas price – from 25 up to 50 € per tonne CO_2 for the natural gas fired IRCC. Of the evaluated more new, and therefore less validated technologies, CLC (Chemical Looping Combustion) appear promising but requiring more R&D. By the end of year 4 a public version of the evaluation and benchmarking report has been issued on the ENCAP Website.

A study has been performed on how higher efficiencies for future power plants, due to ongoing technical developments of e.g. gas turbines and steam cycles (higher steam parameters), may influence key figures for power plant concepts with CO_2 capture technologies developed in ENCAP. The future developments in this area will reduce the overall CO_2 emissions and additional fuel needed for CO_2 captures, and show generally positive effect on additional investment costs, additional electricity generation cost and CO_2 avoidance costs.

Investigations of how large-scale introduction of CO_2 capture and storage will influence the European energy system have been continued. Scenarios without and with CCS as a base for model analysis have been established, taking several useful comments and views from ENCAP industrial partners into account.

In SP2 "**Pre-Combustion Decarbonisation Technologies**" the following has been achieved during year 4:
Numerical simulations of hydrogen combustion with the EDC combustion model and the hydrogen reaction mechanism of Li have been performed on the high-pressure gas turbine model combustor at DLR. The results have been compared to the detailed measurements of DLR on flame structure and temperature, showing good agreement. Additionally, the measurements of overall NOx emissions at DLR could be captured well by the model from SINTEF-ER.

Alstom and Siemens finalized their burner development. Alstom developed a successful preliminary burner design, which fulfils the NOx limits for certain conditions, while Siemens continued the development and testing. However, test facility limits were observed when earlier success full test with natural gas should be repeated with test with H2-rich gas under pressure. Causes and hypotheses were identified and will be verified during year 5 of ENCAP.

Furthermore, in SP2, work on overall power plants with pre-combustion decarbonisation could be finalized. A parameter study by varying the amount of diluents to the fuel gas for NOx control has been performed to identify its effects on overall power and efficiency of the concepts. Final technical documentation has been prepared.

During year 4, the activities of SP3 "**OxyFuel Boiler Technologies**" have mainly been related to the experimental work carried out in WP 3.5 with testing in the 500 kW test rig in Stuttgart. The rig was taken into operation at the beginning of year 4 and in total 4 different test campaigns have been performed with two types of coal; lignite from the Lausitz region in Germany and Kleinkopje Premium from South Africa. The rig has been continuously improved between the test campaigns to more closely resemble conditions expected in a real furnace. Tests performed include gas composition measurements along the reactor, temperature profile, SO2, SO3 and NOx measurements. In addition, un-cooled ceramic probes have been exposed to collect deposits and cooled probes have been used for material exposure tests. Ash samples have also been collected. The data is presently under evaluation.

In parallel, the planning by some of the ENCAP partners of the large scale testing activities to be performed in the 30 MWth OxyFuel pilot plant in Schwarze Pumpe in Germany has continued.

The pilot plant is under construction by Vattenfall and is planned to go into test operation in August 2008.

The work in WP 3.3 OxyFuel Greenfield Pulverised Fuel (PF) Coal-Fired Power Plant has been finished and the overall results have been included in a final report. It was concluded that OxyFuel technology applied to ASC PF power plants is one of the most promising routes to CO2 capture, as this technology is predominantly based on well proven, commercially available equipment which can be delivered at low risk. The introduction of OxyFuel technology in bituminous and lignite fired ASC PF power plants to capture CO2 require an indicative additional investment of around 45-60% (based on net power output). Net plant efficiency is in the ENCAP conceptual design studies estimated to be about 36% to 41% (%LHV, as received) for various concepts investigated. Further improvements in oxygen production technologies are expected to lead to a major increase in the plant efficiency. CO2 avoidance cost of around 20€/tonne CO2 avoided can be reached with around 45% increase in the cost of electricity, based on the ENCAP economic assessment criteria.

In SP4 "**Chemical Looping Combustion**", the following has been achieved during year 4:
The CLC-CFB work was completed. Results from Chalmers on their 10 kWth pilot and from ALSTOM 455 MW unit design studies have proven the feasibility of solid fuel conversion, the applicability of low cost material, such as natural ores, and low cycle efficiency penalty (2%, mainly for CO_2 compression). The estimated CO_2 capture cost is lower than 10€/ton.

Feasibility of innovative reactors for gas turbine application has been studied at IFP (rotating reactor) and TNO (membrane assisted reactor). Experimental set-ups have been constructed to validate these new concepts. The results allowed a better understanding of the potential of these technologies. Despite uncertainties raised by the new reactor concepts, feasibility and economical issues were addressed.

Based on all partners' results, a comprehensive review of technologies was performed by Siemens, exhibiting the potential and maturity of CFB CLC concept, and allowing future progress for all studied applications.

In SP5 "**High-Temperature Oxygen Generation for Power Cycles**", the activities during year 4 have mainly been focused on the investigation of the effects of typical flue gas impurities, such as CO2 and SO2, on the performance of selected CAR materials.

In addition, the results of the CAR Process Development Unit testing (performed outside ENCAP) have been monitored in order to understand their possible effects on the overall performance of the scenario "CAR+ OxyFuel" power plant developed in ENCAP.

An extensive reporting work on monitoring all the research activities aiming at the transition of membrane reactors from laboratory to industrial scale applications in the United States and in Europe outside the ENCAP programme has been performed.

During year 4, the partners of SP6 "**Novel Pre-Combustion Capture Concepts**" have continued their investigations related to:

- Components for the most promising cycles previously studied in years 1, 2 and 3, in particular compressors, turbines, combustors and gas separation membranes
- Economic evaluations of promising cycles studied in years 1, 2 and 3, not only in SP6, but also in SP4 on Chemical Looping Combustion
- Continuation of the review of emerging technologies.

With respect to components, the investigations covered preliminary aerodynamic design of compressors for the SCOC-CC and the S-Graz cycles, heat transfer in a turbine for the SCOC-CC cycle and emissions from combustors for natural gas oxy-fuel cycles. These investigations showed the feasibility of implementation of the respective cycles within the scientific state of the art, although not within the current engineering practice. About membranes, some significant scientific work lies ahead, if such devices are to be part of large-scale power plants. Regarding economic evaluations, the CO_2 avoidance cost and the break-even electricity selling price versus specific investment, fuel cost, operation and maintenance cost and capacity factor were calculated for four natural gas oxy-fuel cycles, four IGCC cycles and two auto-thermal reforming cycles studied in year 1 and 2.

Preparations for Large Scale Testing (LST)

During year 4, activities related to large scale testing have focused on discussions related to the contractual arrangements and financing scheme for the LST, updating the partners of the actual design of the pilot plant and to define the measurement data that will be made available for the partners. In addition, a draft of the partners' role in the actual testing has been presented. The plan was to have a final agreement between the owner of the test facility Vattenfall and the ENCAP partners in the autumn 2007. A draft of a cooperation agreement including a description of the data available and the access to rights exist as well as the participation of the ENCAP partners and the financial contribution to the cost for the testing. However, the cooperation agreement has not been able to be signed yet. The plan is that this could be done during the first half of 2008.

Technical seminar

The third ENCAP Technical Seminar was held in Stuttgart in October 2007. The seminar covered progress and results within ENCAP SP1 (Process and Power Systems) and SP6 (Novel Pre-Combustion Capture Concepts). These two sub-projects were judged to be in a phase where results and work merited further attention and where knowledge should be spread within the Consortium. The ENCAP technical advisory committee (ETAC) was present during the seminar and came with valuable comments at the end of the day and in writing after the seminar.

Dissemination and training activities

Dissemination and Training activities within ENCAP are being organised by CERTH/ISFTA. The Website (www.encapco2.org) has been continuously updated with project progress, reports and results. Information about potential upcoming events, training courses and calls for papers are also reported in order to enforce the disseminating knowledge. During year 4, an activity has been initiated to write summaries of selected deliverables from ENCAP and publish these on the website. Additionally, by the end of year 4 a public version of the evaluation and benchmarking report from SP1 has been issued on the ENCAP Website.

A Technical -Workshop, (22-24 January 2008, IFP–Lyon) was organised as a common event of the four major EU funded project dealing with CO_2 capture technologies (ENCAP, CASTOR, CACHET and DYNAMIS). Presentations of the workshop given by ENCAP SP leaders as well as presentations of the other projects are available to the public on the ENCAP project website. (http://www.encapco2.org/proceedings_CECD.htm)

The ENCAP Newsletter Issue N°4 was published and distributed both electronically and in hard copy to a wide target group (industry, academia) and can also be downloaded from the ENCAP website.

During year 4 a large number of scientific publications and presentations have been published, accepted or submitted based on the work in ENCAP. Totally 20 scientific publications have been registered during the year, with different kind of status. Some are submitted as conference abstracts (GHGT9), some are conference/seminar presentations and the others are related to journals (submitted, accepted or published). Out of the 20 a total number of 11 are related to journals, of which 5 are published/accepted.