PERIODIC ACTIVITY REPORT

PROJECT NUMBER	PROJECT ACRONYM	PROJECT FULL NAME
SES6-CT-2004-502666	**ENCAP**	**Enhanced Capture of CO_2**
INSTRUMENT TYPE	PRIORITY NAME	
Integrated project	**Sustainable energy systems**	
DELIVERABLE NUMBER	SUBJECT/TASK	
	Periodic Activity Report, Months 25-36; Year3	
DATE	CONTRIBUTOR(S)	
2007-04-13	**Clas Ekström, Frank Buschsiweke, Marie Anheden, Etienne Lebas, Ilaria Ciattaglia, Alain Féraud, Paraskevas Klimantos**	
PAGES	RESPONSIBLE	
84	**Kristin Jordal, SINTEF Energy Research/Leif Brandels, Vattenfall**	
PROJECT COORDINATOR	PROJECT COORDINATOR ORGANISATION NAME	
Leif Brandels	**Vattenfall AB**	
PERIOD COVERED		DATE OF PREPARATION
From: 2006-03-01	**To : 2007-02-28**	**2007-03-01**
START DATE OF PROJECT	DURATION	REVISION
2004-03-01	**5 years**	

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 EUR 22,171,000. The European Commission supports the project with EUR 10,702,000. ENCAP started in March 2004. The present report summarizes the activities and results during the third year of the project (2006-03-01 to 2007-02-28).

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[2]

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 design and launch 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 pre-combustion 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 the 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 verification in the project.

[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)

[2] Typical estimated capture cost at the startup of ENCAP

Overall conclusions drawn in SP1, as one of the backgrounds, have had a direct bearing on systems recommendations and the choice of technology for the large scale testing that will be conducted during Phase II of the project. This means that the R&D issues on ENCAP that affect processes and systems - in SP2 through SP6 – have been consistently scrutinised in SP1.

During year 3, ENCAP has passed Phase I and entered into Phase II. The project has after a selection of six proposals to large scale testing 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 partners regarding work contribution during the testing and financial contribution has been discussed 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 with the ENCAP SP3 partners. This work will continue during year 4, leading to the actual test phase during the last year of ENCAP. The overall research activity in the project will decrease in Phase II. However research and development will continue in some of the SPs.

Partners involved

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

Some changes in the consortium have occurred during the third project year due to commercial deals between the energy companies Vattenfall and DONG Energy in Denmark concerning the Danish utility Energi E2. This change of partners has no impact on the work in ENCAP when the two new partners will execute the Energi E2 commitments to the project. The French energy company TOTAL France has joined the consortium.

The ENCAP partners are:

Vattenfall*	ALSTOM**	DLR	Chalmers
DONG Energy	Siemens	CERTH/ISFTA	NTNU
RWE Power	Mitsui Babcock	TNO	Universität Paderborn
PPC	Linde	IFP	University of Stuttgart
Statoil	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

Work performed and main results achieved during the third year

In SP1 "**Process and Power Systems**", the following has been achieved year 3:

- Assessment of the impact of in ENCAP developed power plant concepts with CO_2 capture on the economy of power production and in reflection of various qualitative parameters such as availability, operation characteristics, CO_2 quality, and maturity vs. scale-up requirements, R&D needs and technical risks. A first preliminary evaluation and benchmarking has previously been performed, and an updated final comparison and benchmarking is ongoing.
- Investigation of how large-scale introduction of CO_2 capture and storage may influence the European energy system is ongoing since year 1. A database describing all major

European power plants and CO_2 storage and transport options, together with scenarios for expected demands and fuel mixes, are used as input to model simulations. The model outputs are: power plant mix over the next 50 years period, cost data, and CO_2 emissions, for scenarios with and without CCS, starting with each member state, followed by aggregation to EU level.

In SP2 "**Pre-Combustion Decarbonisation Technologies**", numerical simulations of hydrogen combustion with the EDC combustion model and hydrogen reaction mechanisms have been performed on atmospheric and high-pressure cases. In the case of a lifted atmospheric jet flame the choice of reaction mechanism becomes crucial for predicting flame stabilisation, underlining the importance of including proper kinetics in the simulations. For the high-pressure gas turbine model combustor at DLR, 10 different operating conditions at 10 and 20 bar have been simulated. The main features, shape and structure of the high-pressure flame are well captured. Furthermore, in SP2, work is ongoing to finalise the studies of the overall power plants with pre-combustion decarbonisation.

In SP3 "**Oxyfuel Boiler Technologies**", a number of activities related to experimental investigations of oxyfuel fundamentals in the small-scale test rigs and the conceptual development of the full-scale oxyfuel PF and CFB plants have been finished. Combustion tests related to investigation of NOx emission behaviour with staged combustion under simulated oxyfuel conditions have been investigated. Similar reduction behaviour as under air firing has been concluded. The investigated ash and slagging behaviour under oxyfuel and air firing conditions with ENCAP coals have also found to be similar. In the work package related to conceptual design of oxyfuel PF plants, and economic assessment including transport and storage scenarios has been concluded. The layout of the system used for compression and processing of CO2 has been reported together with identification of processes o be included to reach the CO2 purity levels defined for the EOR and ship transport case in the ENCAP guidelines. A RAM analysis has been performed. The conceptual design of the oxyfuel CFB plant has been finished together with the testing in the 100 mm dia. test rig. Activities to reconstruct a 500 kWth test rig at the U Stuttgart for oxyfuel operation has mainly been finished and the functionality of the rig demonstrated. A decision to focus the ENCAP Phase II Large Scale Testing activities on tests in Vattenfall 30 MWth oxyfuel pilot plant in Schwarze Pumpe, Germany has been taken.

In SP4 "**Chemical Looping Combustion**" SINTEF has produced new support materials for NiO giving an enhanced oxygen release rate, but also developed material with fast oxygen release and intermediate oxygen capacity. Solid fuel conversion with oxygen carrier was successfully experienced at Chalmers in a laboratory-fluidized bed. Various coal qualities as well as pet coke have been reacted with different oxide materials. It has been demonstrated that low cost materials, e.g. natural ores, can react with solid fuels in Chemical Looping Combustion. The effect of SO2 and steam in the fluidizing gas has been studied.
A 10 kWth CLC-CFB pilot was constructed at Chalmers for solid fuels conversion. Tests with coal and pet coke have proved the feasibility of the concept. A design for a 455 MWe coal CLC-CFB boiler has been developed and sized by ALSTOM. It shows a very low cycle efficiency penalty (2%, mainly for CO2 compression). The CO2 mitigation cost is lower than 10 EUR/tonCO2.
Feasibility of innovative reactors for gas turbine application has been studied at IFP and TNO. Experimental set-ups have been constructed to validate these concepts. There is a great potential for the CLC combined cycle, as the efficiency calculated by NTNU reaches 52 % with a double reheat gas turbine. The CO2 mitigation cost using this technology would be in the range of 15 to 25 EUR/tonCO2.

During Year 3, the activities of SP5 "**High-Temperature Oxygen Generation for Power Cycle**" were focused on a prosecution of the CAR material development path by means of experimental investigations on performance and stability of selected material compositions and geometries.
In particular, new material compositions were tested and properties compared, looking at the best trade-off between oxygen storage capacity and chemical stability under dynamic process conditions. With these criteria, a composition was selected and a further material optimization from a porosity and geometry point of view was performed.

In SP6 "**Novel Pre-Combustion Capture Concepts**" the focus has been on further evaluation of the previously studied novel concepts. Qualitative, quantitative and economic evaluations have been made. A first assessment has also been made of emerging technologies through a structured screening of different sources in the literature.

Technical seminar on Chemical Looping Combustion
The ENCAP consortium perceives Chemical Looping Combustion (CLC) as a very promising technology for CO2 capture. However, this technology is not as mature as Oxyfuel PF and needs more development. It was therefore found as priority for large scale testing efforts in ENCAP. Instead a technical seminar was held within ENCAP in order to summarise the work done and gain consensus on the way forward for CLC to be ready for large-scale demonstration.
The ENCAP Technical Advisory Committee was present during the seminar and made a summary towards the end of the day, giving their view on CLC and the work performed within ENCAP

Dissemination and training activities
Dissemination and Training activities within ENCAP are being organised by CERTH/ISFTA. The Website has been continuously updated with project's 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. Furthermore CERTH/ISFTA has started updating the architecture of the website for a more easy access to the project results.

A Workshop - Training Seminar (held in Billund, Denmark on March 16th 2006) was organized for ENCAP and the CASTOR project, with more than 100 Registered Participants. The engineering status of available pre- and post-combustion decarbonisation technologies and required research and development efforts was presented.

The ENCAP Newsletter Issue No3 was published and distributed both electronically and in hard copy to a wide target group (EC, Energy Centres, Manufactures, Universities, Decision-Makers, Local Authorities, etc). The Newsletter contains the results obtained during the project implementation and the research efforts on candidate CO_2 pre- and post-combustion capture and CO_2 storage technologies, as presented in the Common ENCAP-CASTOR Training Seminar/Workshop.

Fulfilment of objectives and results
The objectives for the period have been achieved.

1) The development of the pre-combustion technologies and verifications in the tests indicates that the technologies so far meets the capture rates and avoidance costs for most of the technologies.
2) The work in ENCAP has created new and more substantiate knowledge base on the involvement of utilities, manufacturers, test labs and researchers.
3) The development of supporting techniques or new materials and concepts are very promising and mainly according to plan.

4) The development during the first phase of the project has come to a stage were six applications were found relevant for Large Scale Testing in Phase II.
5) The project has found one of the technologies – the first test campaign in the Vattenfall 30 MWth Oxyfuel Pilot Plant – most valid for large scale testing in order to meet the overall goal of verified data for one of the options for recommendation of technology for a Demonstration Power Plant.
6) The milestone "entering into Phase II" has been achieved and the plan for the period Month 37-54 will be drawn according to this.
7) The development and testing in the ENCAP project during the third year has resulted in forty-one deliverables and reports.
8) The project work by the ENCAP partners and the results has been successful with no delays that influence the project plan.