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HiPerCap: a new FP7 project for development and assessment of novel and emerging post-combustion CO_2 capture technologies

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Abstract

The HiPerCap (High Performance Capture) project started 1st January 2014 as a part of the 7th framework program of the European Commission. HiPerCap aims to develop novel post-combustion CO_2 capture technologies and processes which are environmentally benign and have high potential to lead to breakthroughs in energy consumption and overall cost. The project will study process concepts based on absorption, adsorption and membranes. These process concepts will be assessed using a novel methodology for benchmarking with new and emerging technologies, for which limited data are available and the maturity level varies substantially. Based on the assessment, two breakthrough technologies will be selected for more thorough benchmarking against demonstrated state-of-the-art technologies. This paper presents the objectives of the project, expected outcomes, and the results obtained within the first eight months period.

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1. Introduction

A number of studies have concluded that Carbon Capture and Storage (CCS) should play a major role in the effort to mitigate the effect of CO_2 emissions. CCS buys time needed for the transition to sustainable energy systems as it allows for continued use of fossil energy sources without CO_2 emissions.

Though CCS has been advocated for the last 15-20 years, there is only one large scale facility (recently built at Boundary Dam) for the whole CCS chain. In addition to the uncertainty related to storage the main technological issue delaying implementation of CCS is the high cost of capture. There is, therefore, a clear need to keep on developing more cost efficient capture technologies.

There has in recent years been substantial research on CO_2 capture technologies. A number of different process concepts have been suggested and for each concept there is often a great variation of chemicals and materials that may be employed. At present, it can, however, be very difficult to assess the relative performance and potential of different capture technologies. Claims made concerning the performance and potential of a given technology will often rely on many assumptions, and may not be comparable to numbers reported by others. When claims are made concerning future potential of a technology, it is not always clear if thermodynamic and process limitations of the technology are considered and some numbers may be unrealistic.

The FP7 project HiPerCap aims to develop novel post-combustion CO_2 capture technologies and processes which are environmentally benign and have high potential to lead to breakthroughs in energy consumption and overall cost. The project includes all main separation technologies for post-combustion CO_2 capture; absorption, adsorption and membranes. For each technology the project will focus on a chosen set of promising concepts (four for absorption, two for adsorption and two for membranes). Detailed knowledge concerning the chemical binding mechanism is imperative for the development of breakthrough post combustion capture processes. Chemical binding/interaction of CO_2 with different materials is of relevance not only for absorption, but also for adsorption and membrane based separation processes. Therefore, to support the research activities related to absorption, adsorption and membrane technologies, chemical functional groups with high, reversible, capacity to bind CO_2 will be identified. As a starting point, bio-mimicking systems from organic and inorganic chemistry are explored.

A key focus in HiPerCap is to demonstrate the potential of the various capture technologies. This means showing that all key aspects of a technology are feasible and that the technology can provide a real breakthrough in terms of energy use. Though the materials required for the three types of separation technologies studied in this project are different, a synergy between them is the need for development of feasible process concepts based on a similar set of assumptions. This ensures a fair comparison to be made between the various technologies. In so doing, the results of the assessment will identify the priorities for the future development of these materials.

HiPerCap builds on previous FP6 and FP7 CCS projects such as CASTOR, CESAR, OCTAVIUS, NATURALHY, NANOGLOWA, and iCap and RFCS (Research Fund for Coal and Steel[†]) projects such as AGAPUTE and HYDROSEP. Many of the main coordinating research institutes and industrial partners of these projects also take part in HiPerCap, resulting in a very strong consortium.

Firstly, in this paper, a project summary, its concept, its objectives and its organisation are given. Then, the content of each technical work-package and the main achievements after the first 8 months are presented.

† More information: http://cordis.europa.eu/coal-steel-rtd/

2. Project summary and objectives

2.1. HiPerCap overview

Some key aspects of the project are given in Table 1 while the project partners are listed in Table 2.

Table 1. HiPerCap key aspects

Call identifier	FP7 – Energy 2013.5.1.2: New generation high-efficiency capture processes
Duration	1st January 2014 – 31st December 2017
Budget	7.7 million Euro
Partners	16 (13 from 7 EU and associated member states, 1 from Russia, 1 from Canada, 1 from Australia). See Table 2.
Coordinator	SINTEF
Web-page	www.sintef.no/hipercap

Table 2. HiPerCap partners

Short name	Type of company	Country
SINTEF	R&D Organisation	Norway
NTNU	University	Norway
TNO	R&D Organisation	The Netherlands
CSIC	R&D Organisation	Spain
Procedé	R&D Organisation	The Netherlands
CSIRO	R&D Organisation	Australia
TIPS	R&D Organisation	Russia
MAST Carbon International	Engineering company	UK
DNVGL	Engineering company	Norway and The Netherlands
EDF	Power company	France
CNRS	University	France
CO_2 Solutions Inc.	Supplier	Canada
Algae-Tech	Supplier	The Netherlands
E.ON	Power company	UK and Germany
ANDRITZ Energy & Environment	Engineering company	Austria
Gas Natural Fenosa	Power company	Spain

2.2. HiPerCap objectives and organisation

The objectives of the HiPerCap project are the following:

- Develop CO_2 capture processes with the aim of reducing the total efficiency penalty by 25% compared to state-of-the-art capture technology demonstrated in the EU project CESAR and deliver proof-of-concepts for each technology.
- Improve the process designs to reduce capital and operating costs considering aspects such as environmental impact, operability and flexibility, size of equipment, and choice of materials.

- Assess new and emerging technologies and processes for identification/selection of the two most promising breakthrough capture processes.
- Establish a technological roadmap for the further development of the two selected breakthrough capture processes.

In order to fulfil these objectives, HiPerCap is split into five R&D work-packages (WP) as shown in Figure 1. While WP 4, and 5 focus on cross-cutting issues, the three main technology and process development WPs focus on; absorption-, adsorbent-, and membrane based technologies in WP 1, 2, and 3, respectively. Although, the target is that all technologies studied in WP 1-3 will meet a certain energy requirement reduction, two of the most promising will be further studied in WP5. The selection of technologies for WP5 will be based on the assessment carried out in WP4 and decisions made in the project consortium. In WP5, work will be carried out to develop a roadmap for the two chosen technologies in order to prepare them for testing at industrial pilot-scale. Work will also be done on more detailed benchmarking of these chosen concepts in WP4. Each work-package is described in more detail in the following sections.

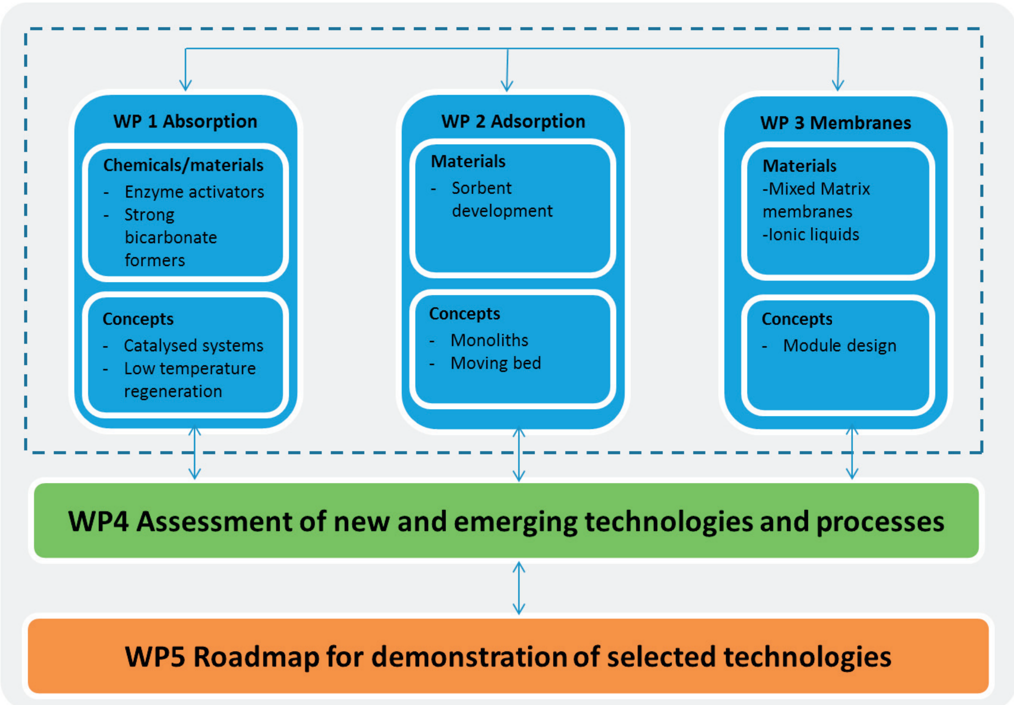

Figure 1. HiPerCap project concept

2.3. WP1 Absorption based technologies

Within this work-package four novel absorption concepts will be explored: Enzyme catalysis of CO_2 absorption, precipitating solvent systems, strong bicarbonate forming solvents and combined CO_2 absorption with CO_2 utilization in the form of algae production. All these are novel ideas that have the potential to create a breakthrough. These concepts have still to be demonstrated in a complete capture process.

For the enzyme catalysis case, a process in which the enzyme is separated using an advanced filtration process prior to the regeneration of the loaded solvent will be developed in order to avoid the general challenge with heat stability of the enzymes. A process using inorganic solvent systems forming solids during the absorption/stripping cycle will be developed. The precipitating systems can achieve higher CO_2 loadings than non-precipitating systems, which is in itself an advantage. Next to that, due to inorganic nature of the solvent, fewer problems related to emission and solvent degradation can be expected. One of the challenges is to develop a process designed to handle slurries.

Continuing work on solvent systems containing strong bicarbonate formers as AMP in the CESAR project, even stronger bicarbonate formers will be studied and associated optimized process concepts will be developed.

Finally, one task in WP1 is devoted to utilization of CO_2 for algae production. The main focus of this task is to develop an integrated system based on using promoted absorption systems to capture CO_2 directly from flue gas in a counter current contactor and using algae to remove the CO_2 from this solution (the CO_2 being present as bicarbonate). This would lead to the regeneration of the solvent in such a way that this can be reused for the absorption of the CO_2. With such a concept one can minimize the energy needed to regenerate the CO_2 and in the same time create additional value by converting a waste product in to useful products. Though the technology will be assessed, it will not be directly compared with others concepts in HiPerCap since it is a hybrid CO_2 capture and utilization concept mostly aimed for smaller scale CO_2 emitters.

2.4. WP2 Adsorption based technologies

Within this work-package solid adsorbents applicable for moving bed reactors and a structured solid monolith sorbent for fixed-bed reactors will be developed. Then post-combustion CO_2 capture concepts with optimized heat-integration and low pressure-drop will be proposed for both types of adsorbents.

The advantages of using adsorbent based processes for post-combustion CO_2 capture compared to amine based processes are related to higher cyclic capacity on a volume basis, lower heating requirements, dry process, and zero emission of harmful chemicals. However, as adsorption based technology for post-combustion CO_2 capture has not yet been deployed at industrial scale there exist limited process design and economic analysis due to the lack of sufficient data on solid sorbent performance in various contactor configurations under realistic conditions. The main challenges are related to issues like heat management, pressure drop, sorbent attrition, and obtaining proper kinetic data. These issues will be addressed in HiPerCap.

2.5. WP3 Membrane based technologies

Within this work-package two types of membranes and associated post-combustion CO_2 capture concepts will be developed. These two types of membranes are 1) high flux mixed matrix membrane based on incorporation of nanoparticles in a polymer and 2) supported ionic liquid membranes. In the latter case two different types of membranes will be studied, but a process concept will only be developed for the most promising.

Membranes have a significant opportunity to be a low-cost, low-energy solution for flue gas CO_2 capture. Facilitated transport mechanism, which is realized both in functionalized hybrid (nanocomposite) membranes and in supported ionic liquid membranes (SILMs), enables membranes to break through the so-called permeance-selectivity ‘trade-off’ line. However, still a lot of effort is needed in order to develop stable membranes for large scale applications.

2.6. WP4 Assessment of capture technologies and WP5 Technological roadmap for development of CO_2 capture technologies

The various technologies and associated process concepts addressed in WPs 1-3 will be assessed using a novel methodology. This methodology will be designed specifically for comparing new and emerging technologies, for which limited data is available and the maturity level varies substantially. Based on the relative performance using various performance indicators, a selection of two breakthrough technologies will be made. Those two technologies will be further studied in order to do a more thorough benchmarking against demonstrated state-of-the-art technologies. A technological roadmap, based on a thorough gap analysis, for industrial demonstration of the two technologies will finally be established.

3. Preliminary Results

Within WP1 a literature review of recent work related to laboratory and computational investigations of the performance of different bicarbonate forming amines has been conducted. Several factors influence bicarbonate/carbamate formation such as steric effects, intramolecular hydrogen bonding and basicity of the amine nitrogen atom. Steric hindrance has generally been seen to increase bicarbonate formation. Introducing steric hindrance could also influence basicity. Various tertiary amines and sterically hindered amines have been evaluated by different research groups (see for example [1]-[7]). Some trends relating molecular structure to performance are reviewed, however, it is seen that such considerations are complex and no single feature can be used to predict the CO_2 absorption capabilities. It was shown that there is a trade-off between the desired solvent properties so an ideal amine fulfilling all requirements is highly unlikely. The review has shown that more work is still needed in order to be able to predict the behaviour of an amine by changing the molecular structure. Experimental testing is often time consuming, in addition new chemicals are not always available. Therefore, a quantum chemical model able to predict different properties of selected amines (for example, basicity (pK_a), carbamate stability (for primary and secondary sterically hindered amines), and free energy of solvation) based on molecular structure is necessary. In this project, a relatively simple computational model based on quantum chemical calculations and the concept of isodesmic reactions has been tested. pK_a and energies of solvation have been calculated for selected amines. So far, a list of promising amine candidates for experimental testing in the project is proposed.

Within WP2, during this starting period, some partners have been involved in the sorbent development and preliminary characterization of the produced materials by means of adsorption isotherms of the main flue gas components (N_2, CO_2, H_2O and O_2) under conditions relevant to post-combustion capture. Focus has been carbon based sorbents prepared from a wide range of precursors including phenolic resins and biomass wastes and under different conformations (beads, granules or monoliths). Carbon adsorbents possess appealing features for CO_2 capture purposes such as lower cost, ease of regeneration, water tolerance, availability and durability. Particular attention is being paid to water vapour adsorption on the samples and the impact it may have on the CO_2 capture performance of the sorbent under post-combustion capture conditions. From these tests a preliminary screening of the most promising materials for this particular application is being set up. It is however too early to anticipate definite results.

A preliminary proposal for assessment methodology to be used to assess the technologies under development in WPs 1-3 has been established within WP4. A two stage approach will be used. The first step will be a screening stage with some minimum criteria for the novel technologies to achieve in order to be considered for further assessment. A guideline for minimum requirements will be drafted and agreed in 2014. As the uncertainty levels for the various technologies addressed in HiPerCap are considerably different, it is crucial to consider uncertainty in the collected data as part of the assessment and comparison. Furthermore, it has been decided to focus on three Key Performance Criteria (1. Energy, 2. Environment, and 3. Costs), which will be made up of key performance indicators (KPI) like for example:

1. Energy: Heat and electrical energy use
2. Environmental: Noise, cooling water usage, waste, emissions to air, emissions to water, footprint, and construction. As environmentally benign technologies are focused in HiPerCap, the environmental KPIs are important.
3. Costs: More qualitative based indicators related to CAPEX, maintenance/material use and energy for the major equipment. An in depth cost assessment will not be undertaken, as the uncertainty is expected to be very high and hence of reduced value.

Finally, it has been decided to use a coal fired power plant based on the European Benchmarking Taskforce (EBTF) work [9] as the basis for capture and developing the quantitative cases for the HiPerCap project. However, other CO_2 sources will be considered for technologies that are more suited to these in parallel to the chosen KPI calculation method in a semi-quantitative or qualitative way.

Dissemination of the results from the project is important and in HiPerCap arrangement of 2 workshops is planned, one in Australia in 2015 and one in Europe in 2017. So far preparations for the first workshop in Australia have been conducted. The aim of this first workshop is to present and discuss the results of the project and other CCS projects in Europe and Australia. Four major themes adapted from the four major work-packages in HiPerCap are covered. Based on the presentations, three sessions are devoted for discussion of recent trends for technology development within the three major types of separation as well as methodologies for technology assessment and benchmarking. The presentations will be by invited speakers only, but the workshop is open for the public to attend.

This workshop will be an excellent occasion to create synergies on CCS between R&D organisations and industry from Europe and Australia. The workshop will take place on 25th -27th March 2015 in Melbourne in Australia and will be hosted by CSIRO in Australia.

4. Conclusions

The current status of the 7th framework project HiperCap is described in the present paper. The four year project, which started in January this year (2014), is focusing on various technologies for post-combustion CO_2 capture. All three main types of separation methods (absorption, adsorption, and membrane) are covered and the main expected outcome of the project is:

- Novel capture concepts developed and documented, ready for pilot testing
  - The project will focus on complete capture concepts; thus emphasizing the utilization of novel materials in a real process environment
  - Roadmap for demonstration and qualification of the capture technologies and processes
- Methodology for assessment and comparison of capture technologies
  - How to compare new technologies with existing ones on a fair basis, e.g.:
    - Absorbers, membranes and adsorbent concepts compared based on large (industrial) scale application
    - Energy requirement (OPEX) based on process simulations
    - Up-scaling challenges and efforts needed for further development
    - Large scale flexibility and operability challenges
- Comparison with state-of-the-art CO_2 capture technologies
  - Technologies developed in the project will be compared with state-of –the-art first generation technologies and/or technologies demonstrated at least at industrial pilot scale

Some preliminary results are presented in the present paper as well as some information about a workshop organised in March 2015 in Melbourne in Australia as a major dissemination activity in the project.

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