Advanced Solid Cycle with Efficient Novel technologies

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1. PUBLISHABLE SUMMARY

1.1 SUMMARY DESCRIPTION OF PROJECT CONTEXT AND OBJECTIVES

ASCENT will provide a robust proof-of-concept of three related high temperature processes; each will lead to a step-change in efficiency of carbon removal in three types of pre-combustion capture, producing the hydrogen needed for highly efficient low-carbon power production. The essential feature linking the three technologies is the use of a high temperature solid sorbent for the simultaneous separation of CO_2 during conversion of other carbon containing gases (CO and CH_4) into H_2. Each technology has the ability to provide a step-change in efficiency because they all separate the CO_2 at elevated temperatures (>300°C) providing for more efficient heat integration options not available in technologies where the separation occurs at lower temperatures.

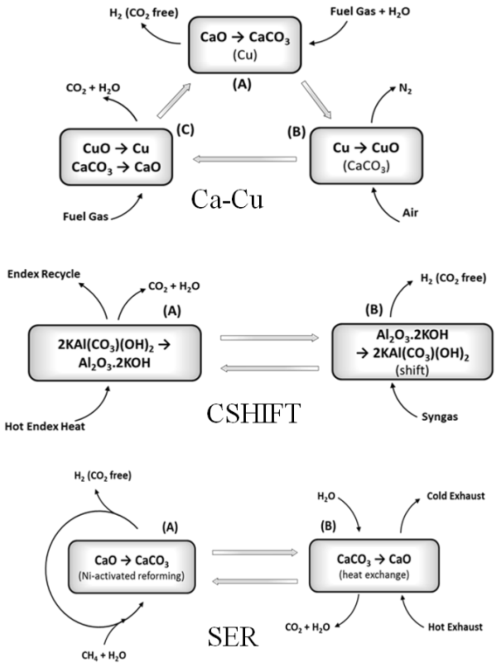

Figure 1 ASCENT Technologies

The synergies between the three technologies are strong, allowing both multiple interactions between the different work packages and allowing a consistent framework for cross-cutting activities across all the technologies. Each technology will be proved, during the project, under industrially relevant conditions of pressure and temperature, at a scale that allows the use of industrially relevant materials that can be manufactured at a scale needed for real implementation. This represents a necessary step to be taken for each of the technologies before setting out on the route to future demonstration level activities. ASCENT, **A**dvanced **S**olid **C**ycles with **E**fficient **N**ovel **T**echnologies, addresses the need for original ideas to reduce the energy penalty associated with capturing carbon dioxide during power generation, and create a sustainable market for low carbon emission power with low associated energy penalties. There are technical objectives that are targets for all three technology lines, and specific objectives related to the details of those technologies. The lead technical objective for each of the three technologies is to provide a robust proof-of-concept with industrially relevant conditions and materials at a scale where a platform for future demonstration is established. The project is divided into 8 work-packages (WP): WP1 takes a broad approach and examines the potential merits of benchmarks and benchmarking for evaluating and comparing the performance of the three investigated processes to set industry performance targets. WP2, WP3 and WP4 are respectively addressed to the investigations needed to develop the innovations which are at the core of ASCENT: proof of concept of Ca-Cu, CSHIFT and SER looping at industrially relevant experimental conditions. The main gaps in terms of safety for the different technology lines is being identified in WP5 and recommendations outlined for the safe deployment and operation of these technology lines. In WP6 dissemination strategy of the main results achieved in ASCENT has been planned. Exploitation analysis studied in WP7 has been planned in strict connection with the dissemination work package. Finally, WP 8 deals with management that has been carried out according to standard procedures and a straightforward management structure.

1.2 DESCRIPTION OF THE WORK PERFORMED AND THE MAIN RESULTS ACHIEVED

In this first reporting period the synergies between the ASCENT technologies have been highlighted in order to strengthen the complementarities between the skills among the work

packages which compose the project. The kick off meeting and the '*synergy*' workshop scheduled at month 8 (October 2014) has helped to harmonised the tasks within the project.
The benchmark plants for power and hydrogen production without CO_2 capture and with CO_2 capture with reference technologies have been, indeed, defined in the **WP1**. For these plants the mass and energy balances have been calculated and the economic performance evaluated, providing a cost of the electricity and of the hydrogen produced and of the CO_2 avoided. In particular, the following plants have been considered:

- Natural gas combined cycle (NGCC) without CO2 capture,
- NGCC with post-combustion CO2 capture by MEA chemical absorption process,
- NGCC with pre-combustion CO2 capture by Auto-thermal reforming and chemical absorption MDEA processes,
- natural gas solid oxide fuel cell (SOFC)-based power plant without CO2 capture,
- natural gas SOFC-based power plant with CO2 capture by low temperature CO2 separation,
- coal-fed integrated gasification combined cycle (IGCC) without CO2 capture,
- coal-fed integrated gasification combined cycle with CO2 capture by physical absorption by Selexol process,
- natural gas fired tubular reforming (FTR) without CO2 capture,
- natural gas FTR with capture of CO2 in syngas by MDEA process and natural gas-fired FTR burners (mid capture case),
- natural gas fired tubular reforming with capture of CO2 in syngas by MDEA process and hydrogen-fired FTR burners (high capture case).

Activity on the process integration of the ASCENT technologies in power plants has also been initiated. Preliminary plant configurations have been proposed for all the Ascent technologies, indicating the likely operating conditions of the Ascent processes. The first process simulations have been performed for NGCC power plants integrating SER and Ca-Cu Ascent technologies.
During this reporting period, the development of the conceptual design of the Cu-Ca process was carried out and delivered (D2.1) in **WP2**. The resolution of the mass and energy balances of the process served as a guidance for the development of suitable materials to run the process. Several synthesis routes were explored for the CO2 sorbents, for the Cu-based materials and for the combined CaO-CuO materials, and the solids produced have been extensively tested in the TGA apparatus available by the partners from the WP. At the end of the reporting period one Cu-based material was selected to be pelletized and produced at higher scale, to test the chemical and mechanical stability of the material in pellet form. In parallel, a CaO-based sorbent is being scaled up and agglomerated. The testing of a commercial Ni-based catalyst under relevant conditions for the process revealed that the catalyst presents sufficient activity for the reforming reaction even after successive oxidation/reduction cycles. Efforts on reactor modeling were started and there are already available 1-D models suitable to predict the evolution of gas composition and reactors temperature profiles along the diverse stages of the process.
The work performed, in the **WP3** so far has been on several issues. Initially we mapped and argued for a class of sorbents that we would follow further in the CSHIFT work package. So called hydrotalcites and MgO based materials will be looked at and optimized further. Work has been performed on pelletisation for pressurized fluidized bed reactors and a lab scale pressurized fluidized reactor has been commissioned. In-situ DRIFTS and XRD studies have been performed on as received and CO_2/steam loaded samples in order to obtain insight into bonding modes of CO_2 and structure. Fixed bed tests to assess CO_2 capacity at elevated pressure, and also in the presence of H_2S, have been initiated. Initial modelling developments have been carried out. A Random Pore Model has been put forth among others.
The work performed in **WP4** has been focused on the four following topics:

- Determination of material performance criteria and operating process conditions
- Development of CaO-based sorbent, reforming catalysts and combined materials (CSCM)

- Measurement of attrition index of selected materials
- Modelling of the SER looping process

The performance criteria of the combined sorbent/catalyst materials to be developed have been assessed and the ranges of the different values have been determined. The main defined criteria are the percentage of active CaO in the sorbent, the maximum percentage of Ni in the CSCM, the minimum sorption capacity of the CSCM, the attrition index of the CSCM, and the cost. Operating process parameters windows have also been defined for two different reactor configurations. These data have been compiled in deliverable D4.1.

The material development research has followed the following routes:

- Development of a hydrothermal method using hydroxide precursors to produce a stable mayenite supported CaO-based sorbent
- Development of a wet mixing method using nitrate or acetate precursors to produce a stable mayenite supported CaO-based sorbent
- Development of a wet mixing method using nitrate, acetate or citrate precursors to produce a stable CaO-based sorbent supported on a coal fly-ash cement

The developed materials have been characterized and tested extensively. So far the best results regarding cycle stability and sorption capacity have been obtained for the mayenite supported sorbents. Two different production methods are under investigation for up-scaling.

As far as the combined sorbent-catalyst materials are concerned, two main routes have been investigated:

- Mechanical mixing of sorbent and catalyst powders, followed by agglomeration
- Ni-impregnation of sorbent material, followed by agglomeration
- Direct chemical synthesis of combined material, followed by agglomeration

From the results obtained so far, the mechanical mixing route seems to be more suited than the two others. Pellets or granules using commercial catalysts have not shown the expected SER performance in terms of stability, probably due to different supports used in these materials. The research work has then been directed towards the production of a Ni-catalyst using the same support as the sorbent, i.e. mayenite. Multi-cycle tests of the catalyst in SER conditions have shown very promising results for a future combination with a mayenite-supported sorbent.

In parallel, a mayenite-supported sorbent has been tested for SER tests in a laboratory scale fluidized bed reactor, mixed with a commercial reforming catalyst in a separated two-particle system. The results were very satisfactory showing good SER performance in relevant process conditions. A high temperature test bench has also been developed to measure the attrition index of the materials and test the mechanical stability for use in fluidized bed reactors. The results obtained for an agglomerated mayenite-based sorbent are promising but still over the target value fixed.

Finally, a sorbent-catalyst bi-functional particle model is under development in WP4. The starting point is an existing particle grain model for sorbent alone. After definition of the CO_2 sorption activity (sorption capacity and kinetic rate), the optimal catalyst loading of the sorbent particle and the relative distribution of sorbent and catalyst in the particle volume have been studied. The particle model has been improved by implementing the steam reforming and water gas shift reaction mechanisms and kinetic expressions. Simulation work is on-going.

The **WP5** aims at performing a technological risk assessment, the environmental life cycle assessment (LCA) and the socio-economic analysis (SEA) of the ASCENT technologies. The main results achieved for WP5 during this reporting period concerns the task 5.1:

- the steering committee for WP5 has been constituted; preliminary goal and scope has been defined for the safety and sustainability assessment;
- a preliminary data collection framework has been done for LCA and safety analysis,
- the perimeter of the technologies to be studied and compared (ASCENT & REFERENCE cases) has been defined.

- a framework on HSE and economic issues for the ASCENT technologies has been developed and a preliminary inputs were collected from the different WPs,
- global methodologies and plans for carrying out the different impact assessments have been made.

The different results are discussed in detail in section 2.2.5 in this report. Three documents could be cited for this reporting period for WP5 and these documents are available in the project portal:
Presentation of WP5 at the kick off meeting (M1);

- Presentation and ASCENT synergies workshop held at ECN on the 16th and 17th of October 2014 (M6);
- Deliverable D5.1 'Preliminary goal and scope definition and data collection framework and management' (M12).

In this first reporting period, the main efforts within the **WP6 and WP7** have been mainly focused in the set-up of the project dissemination and exploitation plans. Communicating early the goal of ASCENT may increase, indeed, its potential impact improving exploitation of the foreground. In this regards, the project management team has presented the scope and the main objectives of ASCENT in the first Australian–Europe workshop held in Sydney in order to make audience be aware of project aims. Australian partners have also attended the workshop presenting their contribution to the project. In order to aware the consortium of the synergies internal to the consortium, a kick off meeting has been organised in Rome. An important outcome of this event was the agreement of the specification of communication-related strategy which involves the management of the Dissemination Plan approval phase and the coordination of feedback obtained regarding the communication activities. A template of project status reporting has been also presented and agreed with the consortium during the kick off meeting in order to manage and implement the advances during the whole project lifetime. Feedback from the consortium regarding dissemination material was, indeed, encouraged in order to share knowledge among the consortium and stakeholders as wide as possible in an open access mode. With this regards, a web site has been implemented to share internally documents and externally dissemination materials. Moreover the web site enables the registration of users in order to provide opinion leaders and potential stakeholders with public documents.

1.3 EXPECTED FINAL RESULTS AND THEIR POTENTIAL IMPACT AND USE

A prerequisite for the large scale deployment of CCS is the demonstration of the technical and economical feasibility of innovative low carbon emission technologies at prototype scale. For this purpose, the ASCENT project intends to investigate and develop more efficient and cost competitive pre-combustion technologies and new materials for CO2 capture. ASCENT is addressed to the field of environmentally benign technologies that is characterised by an important and increasing role of SMEs, either involved as end users of the relevant technologies, or as technology developers: for such reason, dissemination actions are envisaged in the project work plan, particularly addressed to SMEs, and the implementation of web-site for the broad dissemination of the innovations. Exploitation of the project results is based on a detailed exploitation roadmap to be developed in WP7 (Exploitation of the developed sorbent technologies). This project targets to develop products that partners would be ready to commercialize as extension of the actual portfolio or as new lines. These companies have then organized the exploitation roadmap coordinated by partner company CALIX. The roadmap will consider:

- Market analysis and expected impact of the ASCENT solutions, in terms of catalysts, sorbents and reactors prototypes.
- Exploitation Business Plan for ASCENT solutions.
- Issues related to the management of intellectual property rights.
- Specification of the contracts for exploitation of the ASCENT solutions