EU FP7 Project

SUCCESS

Industrial steam generation with 100% carbon capture and insignificant efficiency penalty - Scale-Up of oxygen Carrier for Chemical-looping combustion using Environmentally SuStainable materials

Abstract

Chemical-looping combustion (CLC) has unique potential for reducing energy and cost penalty for CO_2 capture, as it avoids the costly gas separation of other CO_2 capture technologies. Early deployment is seen in natural gas steam generation, where gas-to-steam efficiency penalty with CLC is below 1%-point compared to 15%-points with amine scrubbing and 8%-points with oxyfuel combustion, all for 95% capture rate. Reduction of the CO_2 avoidance cost of 60% compared to amine scrubbing post combustion capture results from higher efficiency. An absolute necessity for the scale-up of reactors for this technology is the availability of adequate oxygen carrier material. SUCCESS will assure scale-up of oxygen-carrier production to the 100 tonne scale, as well as scale up of technology to 1 MW. Industrially available raw materials will be used to produce environmentally sound oxygen carriers based on two highly successful materials developed of the previous INNOCUOUS project. The work includes,

- i) applying the oxygen carrier production methods at industrially required scale and assuring the adequate performance,
- ii) development of standard for mechanical stability,
- iii) validation operation in four available smaller pilots <150 kW, of significantly different design
- iv) operation with gaseous fuels in a 1 MW pilot plant, representing a scale up of the state of art by one order of magnitude.
- v) detailed studies of reaction mechanisms and fluid-dynamics
- vi) use of results in optimization of a previous design for a 10 MW demonstration plant and techno-economic study of full-scale plant
- vii) assessment of health, safety and environmental issues associated with oxygen carrier handling including reuse or recycling strategies.
- viii) quotations for production of >100 tonnes of material

Combined efforts of key European developers of CLC technology will assure the continued European leadership in this development and bring the technology a major step towards commercialization.

Background on chemical looping combustion

The problem with the carbon capture technologies typically discussed is that gas-gas separation steps occur. This means either CO_2 separation from exhaust gas or synthesis gas, or air separation for subsequent oxy-fuel combustion or gasification. The energy required for gas separation is the major component of the efficiency penalty of these processes. Studies show that with usual technologies, capture and compression of 90% of the CO_2 will cause a loss of between 8 and 14 percentage-points of electric plant efficiency. This reduces the net electricity output by roughly 25% for the same fuel amount and increases the fuel needed and CO_2 produced by roughly 33% for the same net power produced.

Chemical looping combustion (CLC) is a combustion concept where air and fuel are never mixed. Thus, CO_2 is not diluted by N_2 and gas-gas separation is inherently avoided. The principle of CLC is shown in Figure 1. Metal oxides are used to selectively transport oxygen from the air reactor (AR) to the fuel reactor (FR). Ideally, the FR exhaust stream contains only CO_2 and H_2O while the AR exhaust stream is oxygen-depleted air. This means that **100% of the fuel carbon is captured** as CO_2 available in concentrated form after simple condensation of the steam from the FR exhaust stream. **The total heat release from CLC is equal to that of direct combustion and, thus, the energy penalty is reduced to the CO_2 compression and purification efforts all capture processes will have in common.** This gives CLC a **unique position among the options to capture CO_2** from combustion processes.

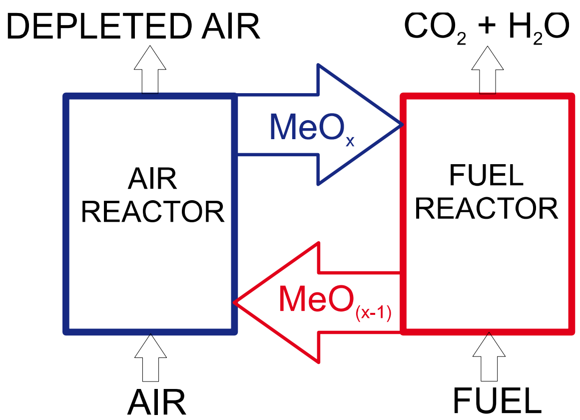

Figure 0.1: Chemical looping combustion (CLC)

The current status of CLC development can be most briefly summarized as follows:

- **CLC for gaseous fuels** at atmospheric pressure was **successfully demonstrated** at small pilot scale (140 kW, Vienna, 2008) and for more than 1000 hours (10 kW, Chalmers, 2008) within the CLC GAS POWER Project (FP6, 2006-2008) **using oxygen carrier materials based on commercially available nickel oxide**.
- Increasing awareness about the safety and environmental risks associated with the use of nickel oxide has led to the investigation and successful development of **suitable non-nickel oxygen carrier materials** in the INNOCUOUS Project (FP7, 2010-2013).
- A **demonstration project for a 10 MW gaseous fuel CLC field pilot plant** has been started in Canada by Cenovus FCCL for **CO_2 ready industrial steam generation**. The design followed in this project is largely the one proposed within CLC GAS POWER. This project is still aiming at using nickel-based oxygen carrier materials.

- More recently, also IFPEN/TOTAL have announced a demonstration project for CLC at a scale of 3 MW or more, and SINTEF ER is currently investigating the possibilities of having a pilot plant at the Test Centre Mongstad (TCM).
- Numerous activities to directly apply CLC to solid fuels are ongoing worldwide. Here, the challenges are still subject to intensive research and time to market will be longer compared to atmospheric pressure gaseous fuel application.

Project objectives

Successful up-scaling of CLC technology is heavily dependent on the up-scaling of two aspects in parallel, namely

- Up-scaling of reactor system
- Up-scaling of particle manufacture

For successful up-scaling of the technology both need to be accomplished in parallel. This new technology has raised a lot of interest world-wide, and today there are several organisations who are in the planning of up-scaling the technology to the 10 MW range, all with a pronounced focus on the up-scaling of the reactor system part. This will, however, require tons of material and it needs to be pointed out that the up-scaling of material production from say 100 kg, using more or less pure and well-defined raw materials, to many tons using raw materials available commercially in large quantities and likely less pure, is associated with several requirements

- A good expertise and experience with evaluating these materials.
- Adequate supply of commercial raw materials.
- Entities capable of large scale production and adequate links between these entities and those with previous experience in production/evaluation of materials.
- Time. The step from laboratory to industrial scale material production along with the transition to less expensive raw materials will take some time for testing and optimization. Therefore, in order to allow for successful technology demonstration, scale-up of material production has to start 2-3 years prior to start-up of demonstration units.

There is clearly a risk that up-scaling of the technology may fail for several reasons if proper scale-up of materials has not been done in parallel,

- Decision on financing demonstration plants may fail for uncertainties on the availability of adequate materials.
- Operation of demonstration plants may fail or be less successful for lack of adequate materials.

The **first key purpose of the project** is, therefore, to **scale-up material production**, making oxygen-carrier material with high performance available for use in demonstration plants. This material may then:

- Be the main material to be used in potential future demonstration plants.

- Be one of two or more materials to be used. This will then give the possibility to compare behaviour and performance of different materials. The availability of more than one material will significantly increase the probability of success.
- Be a substitute for a material that should be avoided for HSE reasons, i.e. for nickel-based material.
- Be a substitute for a material that was planned for use, but which has failed in the scale-up phase

The **second key purpose** of the project is to **scale-up CLC system design to 1 MW fuel input**. This will comprise the following steps:

- Comparative testing in four different units up to 150 kW featuring different designs.
- Optimization of the CLC system geometry based on a deep understanding of reaction mechanisms and fluid dynamics
- Proof of performance at 1 MW fuel input using an industry-like design of coupled circulating fluidized beds

Thirdly, the **overall potential of the CLC-CCS technology** is assessed based on the new SUCCESS figures for materials and performance and compared to alternative technology, in terms of:

- Health, safety, and environmental implications of material handling and plant operation
- Techno-economic potential for a number of possible applications in industry and power production

SUCCESS will provide substantial R&D for the implementation of CLC for gaseous fuels at a next scale of 10 MW fuel power. The announced 10 MW demonstration projects may rely on material production scaled-up within SUCCESS to the level of delivering quotations of totally 100 tonnes. The timeline of SUCCESS suits with the requirements of these demonstration activities.

Key project objectives

Based on the key purposes above, the following key objectives of SUCCESS can be stated:

1. To produce two ≥ 500 kg batches of scale-up ready materials by Month 27 of the project. These batches will be made of commercially available raw materials identified during the first year of the project and benchmarked against other oxygen carrier materials using the testing procedures developed.
2. Proof of performance for the produced materials in technical laboratory scale up to 150 kW fuel power input will be accomplished.
3. To demonstrate the chemical looping combustion technology at 1 MW design fuel power within the project.
4. To present an optimized next scale (approximately 10 MW fuel power input) design based on detailed reaction and fluid dynamic models.

To quantify the techno-economic potential in comparison to benchmark cases constituting best available technology in the sense of the European Benchmarking Task Force. The analysis considers specific health, safety and environmental aspects of the technology.

Specific research questions

The following specific **research questions** arise based on the key objectives of SUCCESS:

1. Material provision, scale-up of oxygen carrier production:

- How are the **non-nickel oxygen carrier materials**, which were developed in INNOCUOUS, best produced at large scale (i.e. batch sizes that are relevant for multi-tonne manufacturing) and from which commercially available raw materials?
- What are the relevant measurable material characteristics to guarantee high performance in continuous long-term operation and what values must be reached by a material in order to qualify as an oxygen carrier (attrition, transport capacity, reactivity)?
- Is there a large scale solution to the question of reuse/recycling/disposal of used oxygen carrier material?

2. Scale-up of CLC system technology:

- Is the currently followed dual fluidized bed design, which is based on the properties and performance characteristics of nickel-based materials, equally suitable for CLC using the non-nickel materials and what changes are necessary to optimize design for the new materials?
- What is the performance at a relevant scale of 1 MW fuel power in terms of fuel conversion and mechanical stability of the oxygen carrier material?

3. Overall technology potential

- What are the costs related to health, safety and environmental protection measures?
- What are the relative incremental operating costs of the capture process in terms of CO_2 avoidance costs for applications such as industrial steam generation, power generation from gaseous or solid fuels, or combined generation of power and hydrogen?

Project consortium

The SUCCESS consortium consists of world-leading institutions in the development of chemical looping technology and is represented by universities, research institutions, technology providers as well as end-users. The consortium as a whole features:

- 9 RTD providers
- 3 Technology providers, and
- 3 End users

Thus, the partnership displays fully complementary competences and guarantees for applied research that is aiming at commercial end-use of chemical looping technology.
Partners of SUCCESS are located in eight Member states of the EU; Austria (2), Belgium (1), France (4), Germany (1), Netherlands (2), Spain (1), Sweden (1) and the United Kingdom (1) as well as in Norway (2).

Since the SUCCESS consortium emerged from the existing 7thFP INNOCUOUS project, the core of the partners has already proven its capacity for excellent teamwork and high-level research activities. All of the partners exhibit a long experience with execution of EU projects and SUCCESS will unite Europe’s most important institutions in the field of chemical looping combustion. Thus, the outcome of SUCCESS will again strengthen Europe's leading position in the field of chemical looping, the most efficient capture technology for CCS applications.

The partners are:

- Vienna University of Technology/RTD (Coordinator, Austria)
- Chalmers University of Technology/RTD (Sweden)
- Consejo Superior de Investigaciones Científicas (CSIC)/RTD (Spain)
- IFP Energie nouvelles/RTD (France)
- Institut National Polytechnique de Toulouse (INPT-IMFT)/RTD (France)
- SINTEF Energi AS/RTD (Norway)
- Darmstadt University of Technology/RTD (Germany)
- VITO – Flemish Institute for Technological Research/RTD (Belgium)
- Eurosupport Advanced Materials (Netherlands)
- Johnson Matthey (United Kingdom)
- Bertsch Energy (Austria)
- Electricié de France (France)
- Shell Global Solutions (Netherlands)
- TOTAL (France)
- Vienna University of Natural Resources and Life Sciences/RTD (Austria)

Available pilot plants

Different CLC system design options have been developed by different European research institutions. Each of these units shows specific advantages regarding specific inventories, solids circulation rates, analytical equipment and possible range of operating parameters. A brief summary is given in the following table:

Operator	Fuel power	Fuel	Special features
Chalmers	10 kW	Natural gas	• Overnight operation • High gas velocities for attrition testing
Vienna	120 kW	NG, CO, H_2, hydrocarbons, H_2S	• High solids circulation rates • Solids sampling for determination of mean degree of oxidation • Operation with higher hydrocarbons and sulphur
IFPEN/ TOTAL	10 kW	CH_4, CO, H_2	• L-Valves for control of solids flow rate • Control of gas and solids residence times • 3 reactors (2xAR, 1FR)
SINTEF ER	150 kW	Natural gas	• Routing of particle flow possible • Internal recirculation of particles possible • Gas velocities representative for industrial CFBs • Commissioning mid 2013
TUD	1 MW	Natural gas	• Fully refractory lined reactors • Post combustion chamber using pure oxygen • J-valve or screw conveyor can be used to transport solids from AR to FR • Pilot plant will be adapted during SUCCESS to operate with natural gas
Vienna	10 MW	Cold flow model	• Scaled model of 10 MW CLC reactor design • Detailed determination of solid flow rates

Time plan

Project start: September 1st, 2013

Project End: February 28th, 2017

The screening of suitable raw materials for the oxygen carrier production start at the beginning of the project. The scale-up of the production process is planned to be finished in month 24 of the project, i.e. fall 2015.

After production of the large batches, testing in the pilot plants starts. This is planned to be finished with the demonstration of CLC at 1 MW fuel power input at the end of the project.

In parallel, HSE and techno-economic assessment starts, evaluating the whole process including oxygen carrier production, plant operation and oxygen carrier recycling/reuse/disposal. Results will be summarized in a life time assessment study.