DemoCLOCK

Demonstration of a cost-effective CO_2 capture technology

Array Industries - CTI - ECN - Elcogas - Foster Wheeler - IEIA - Politecnico di Milano - SINTEF - TU/e - VITO

DEMO CLOCK

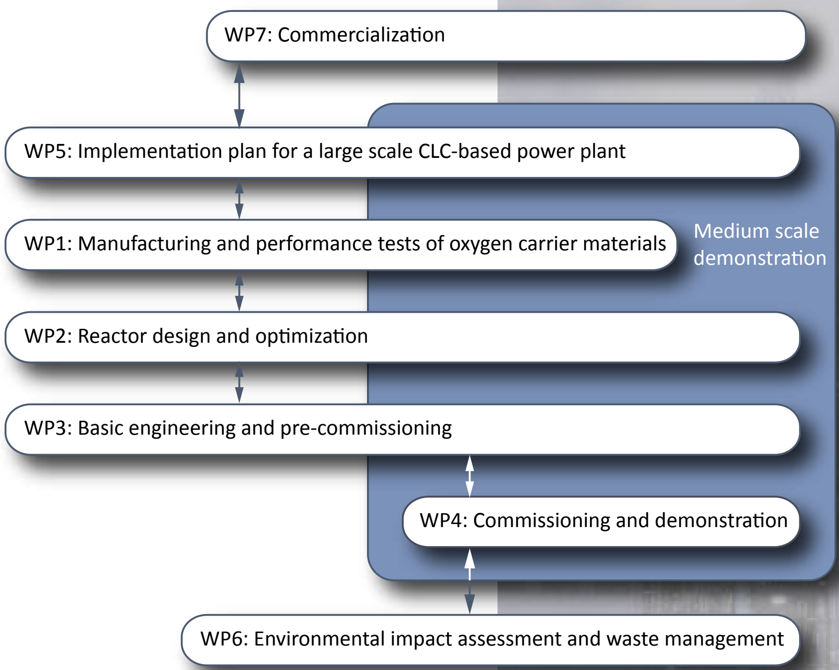
Introduction

The main objective of DemoCLOCK is to demonstrate the technical, economic and environmental feasibility of implementing packed bed Chemical Looping Combustion in large-scale power plants.

A medium sized (500 kW) fixed bed reactor will be designed, build and operated in integration with IGCC power plant of Elcogas in Puertollano, Spain. The Packed Bed Reactor Chemical Looping Combustion (PBR-CLC) will be used to convert carbonaceous feedstock to high energy streams with carbon dioxide capture.

The ultimate objective is the demonstration for proof of feasibility of this technology, hence all tasks are related to the medium scale demonstration of the 500 kW reactor, which will actually take place in WP4 “Commissioning & demonstration”. Before demonstration, the oxygen carrier materials are being developed (in WP1), the reactor is designed for this scale (WP2 and WP3), and the reactor needs to be built (WP3). The flow of information between work packages is shown in the following figure.

During the development and operation of the medium scale reactor, information from these workpackages will be fed into the Technology Implementation Plan that will be developed in WP5. To ensure that all health, safety and environmental aspects are taken into account, while designing and building the reactor, an environmental impact and waste management assessment is planned in WP6. In WP7, the commercialisation of the technology will be studied and so its allocation among other benchmark technologies.



A business plan will be established before the end of the project.

Work Package 1

Manufacturing and performance tests of oxygen carrier materials

The quality and availability of materials for the new process needs to be specified and secured. The objective for this work package is to select and develop a suitable oxygen carrier for the operation of a medium sized PBR-CLC.

Lab scale test reactor at Eindhoven University of Technology.

This challenging and ambitious task aims to develop an oxygen carrier which combines: high oxygen transfer capacity, suitable reactivity, kinetics to limit reactor size, shape to support a flow pattern that allows 'intimate' interaction with the fuel (syngas from coal gasification) and air, minimum pressure drop, minimum packing density, acceptable strength to make a lifetime of above 20.000 hours of operation possible, and sulphur poisoning resistance in the sense that the other targets can be met.

SINTEF and TU/e have selected potential materials, based on the criteria coming from the reactor design. CTI has produced the required shaped blends of minerals, which have been tested and evaluated both in the lab-scale reactor at TU/e and SINTEF, and at ECN for sulphur tolerance. At VITO, detailed physico-chemical characterization of the oxygen carriers has been performed, including the mechanical performance of the material after several oxidation-reduction cycles.

The development of new oxygen carrier materials for fixed bed CLC operation is coming to an end in the project, and has resulted in materials that reach the proposed target. Consequentially, the required amount of oxygen carrier material for the 500 kW test facility will be then produced by CTI.

The knowledge gained in the first project half on the oxygen carrier material for PBR- CLC, has learned there is still room for improvement, and will give direction to future developments.

Sintered ilmenite based granules

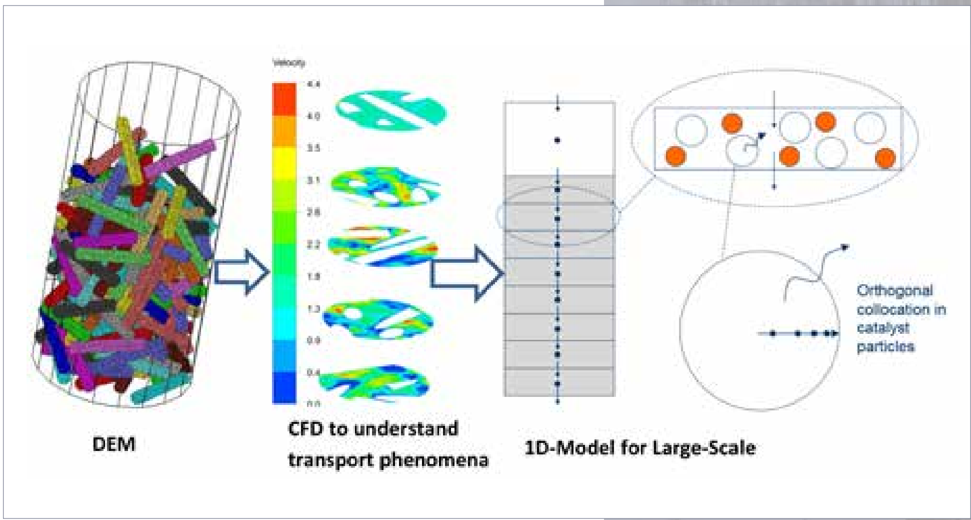
Work Package 2

Reactor design and optimization

Computer simulations of the PBR-CLC operation have been developed to assist the design and performance optimization of the new reactors, as well as the further selection of the most appropriate operational strategies.

The main tools are special-purpose reactor simulators (1D models) developed independently by SINTEF and by TU/e. These simulators predict the evolution of temperatures, pressure and gas compositions in the reactor during operation. It is thus possible to decide on reactor design, feed conditions, cycle times, etc. before actually constructing the reactor.

In addition to the special-purpose reactor simulators, detailed simulations of flow, pressure drop, heat- and mass transfer in packing materials have been performed using state-of-the-art Computational Fluid Dynamics (CFD) and the Discrete Element Method (DEM). These simulations provide detailed input to the special-purpose reactor simulators regarding the performance of particular types of packing material, such as the shape of oxygen carrier, thermal losses from the reactor and non-uniform flow distribution in the reactor. In particular, the DEM has been adopted to predict the packing structure, while the CFD is then used to obtain pressure drop and heat transfer correlations for the packing material. Different types of oxygen carrier packing such as spherical particle, cylindrical pellets with different aspect ratios, and fluted ring have been compared for the CLC operation. The main scope of these simulations was to select oxygen carrier shapes, which give low pressure drop, higher conversion, no fuel slip and withstand thermal and chemical stresses. The adopted methodology allowed to recommend a pellet shape with a specific aspect ratio to be implemented in the 500 kW demonstration facility.



Work Package 3

Design and realization of DemoCLOCK test facility

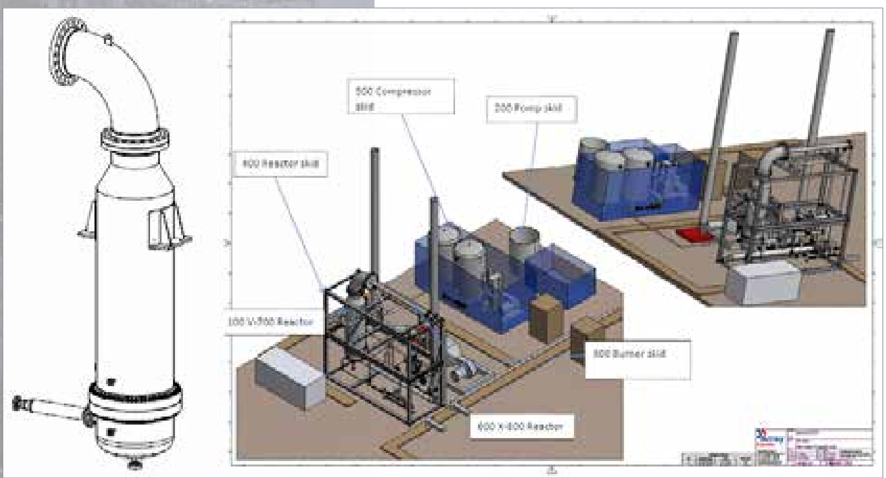
To demonstrate the carbon capture capabilities of the PBR-CLC system and to test and verify the reactor material, a test facility will be installed on the site of Elcogas in Puertollano, Spain. For this purpose, Array will design, manufacture and install the demonstrative PBR-CLC.

The test installation will run on 5 subsequent cycles: oxidation phase (to generate heat by oxidating the reactor bed), purge, reduction phase (to reduce the bed at elevated temperature), purge and heat removal phase (using nitrogen to push out the heat of the reactor). Compressed air and nitrogen must be fed to the reactor at elevated temperature, so a pre-heater is installed between the air compressor/nitrogen feed and the reactor.

The heart of the test facility is the reactor (500 kW). The engineering challenge is the combination of high temperature and pressure; the bed temperature should be able to reach a temperature of 1100°C, while system pressure is around 22 bar. For this combination, a single walled pressure vessel cannot be used. In the current design, the reactor will consist of a pressure carrying outer shell with a large pack of internal insulation. Within this insulation, a gas guiding liner containing the reactor bed pellets is located. Within this liner, the CLC processes will take place. The feed gasses (air, syngas of N_2) will enter the reactor on the bottom side, while the hot gasses (oxygen free air, N_2 or a stream of CO_2 and steam) will leave the reactor on the top side.

Continuous temperature measurement within the reactor bed will be applied to record the traveling of the heat front through the reactor bed.

Drawing of reactorand general arrangement of installation



Downstream the reactor the gasses will be cooled. A gas sampling unit will measure gas compositions, and this data will be available to verify the calculation models implemented in WP1 and WP2.

Work Package 4

Commissioning and demonstration

The main aim of this work package is to successfully complete demonstration tests of a 500 kW CLC fixed bed reactor integrated in the Elcogas IGCC power plant for 3,000 hours. Realisation, installation, and operation of the DemoCLOCK reactor assembly system will be the focus of this work package. The Elcogas IGCC power plant in Puertollano (Spain) utilizes coal as a feedstock and, through gasification and cleaning processes and will provide the DemoCLOCK demonstration with a desulphurised (< 25 ppm) stream of syngas, mainly CO and H_2. The CLC system will not be integrated in the power cycle. The interface of this stream and a compressed air stream with the CLC reactor system will be optimized with the possibility for additional processing of the syngas stream.

An operational time of 3,000 hours is expected to give an acceptable indication of the feasibility of a large-scale CLC power plant with the selected oxygen carrier. During the operation led by Array Industries and ECN, data will be logged on the temperatures, pressures, flows and efficiencies of the different streams and system components. Transient temperature profiles will be measured along the bed in the axial direction, together with the transient changes in gas composition at the reactor outlet and pressure drop along the packed bed. This data will be used to validate the process and reactor models of WP2 and will be fed into WP5, Techno-Economic Assessment. The combination of validated process models and real life operation experience will show the feasibility of CLC fixed bed systems.

Work Package 5

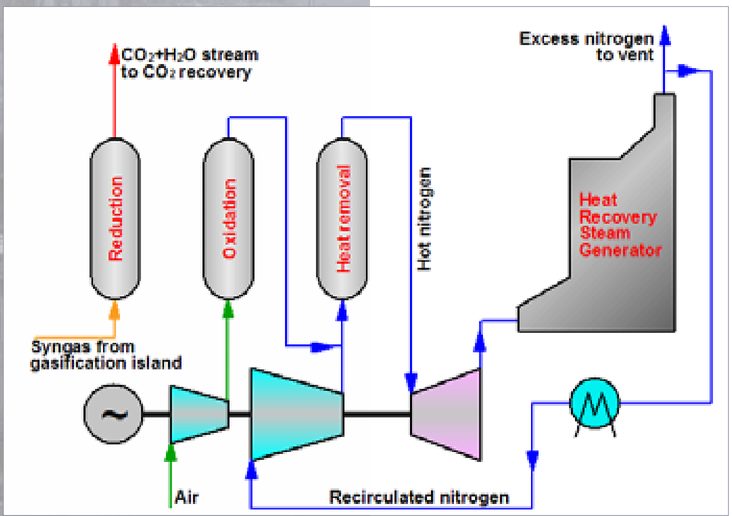
Implementation plan for a large scale CLC-based power plant

One of the main goal of the DemoCLOCK project is to assess the potential of integrating a PBR-CLC system in a large scale coal fired power plant and to tentatively exceed the performance of the current commercial technologies in terms of efficiency and CO_2 capture.

To this purpose, a suitable operating cycle of the PBR-CLC system has been devised aiming at ensuring an appropriate heat management to allow fast reaction kinetics, high temperature and stationary conditions of the outlet streams for an efficient and reliable connection to the power cycle.

An effective way to apply PBR-CLC in a coal fired power plant has also been defined. Different configurations of integrated gasification power cycles were initially considered by Politecnico di Milano and Foster Wheeler. The most promising in terms of efficiency and feasibility is a modified gas turbine combined cycle, operating accordingly to the conceptual plant flow diagram of fig. 1. During the reduction phase, syngas is converted to CO_2 and water by reaction with the metal oxide. CO_2 can be easily recovered for long term storage by separating water by condensation. In the oxidation phase, metal is oxidized by air while heat removal from the hot beds is accomplished by recirculating a nitrogen stream. A conceptual design and optimization of the full scale Integrated Gasification Combined Cycle plant inclusive of the PBR-CLC system has been performed. Basic heat and mass balance of this system has been evaluated by a proper simulation model for steady state conditions.

Conceptual plant flow diagram of a PBR-CLC based combined cycle.



At this stage Politecnico di Milano with the support of Foster Wheeler has successively performed an initial design of the PBR-CLC system. An operating sequence for this system has been devised and its actual dynamic behaviour has been assessed by means of a one dimensional simulation. In the next step, the results of this unsteady state simulation of the PBR-CLC system will be incorporated into the thermal balance of a full-scale power plant.

Work Package 6

Environmental impact assessment and waste management

The main goal of this work package is to assess the safety, life cycle and environmental impact of a full-scale power plant, fired with solid hydrocarbons, with CO_2 captures and based on the new developed PBR-CLC technology.

The results of new PBR-CLC technology assessment will be compared with those of the reference studies for conventional power plants fired with coal/fossil fuels. Thus, the PBR-CLC technology's benefits for future quality of environment and human health will be determined.
The activities within this WP are divided into three tasks.

In the first task, SINTEF will develop a safety impact assessment model, with the scope to evaluate the safety performance of the new PRB-CLC technology. A risk-based methodology will be used to conduct this task.

In the second task, VITO will developthe life cycle assessment (LCA) for all the components used for the construction and installation of a full-scale power plant based on PBR-CLC technology. The objective is to demonstrate the environmental impacts associated with this new process during its lifetime. The results of this assessment will be compared with those of conventional coal-fired power plants. At this stage, the necessary parameters are collected as starting bases for the LCA methodology.

Finally IEIA will investigate the potential, health and environmental hazards related to the implementation of the PBR-CLC system in commercial scale power plant. The Environmental Impact Assessment will focus on the environmental and health aspects of the coal based process and relevant involved materials will be evaluated. The assessment's results will be compared with those of conventional coal-fired power plants, and in particular the impact on air, surface water, and noise.

Work package 7

Commercialization

The main objective of this work package, led by Foster Wheeler Italiana, is to prepare the commercialization of the new CLC technology. DemoCLOCK Consortium will to organize and hold some workshops with potential industrial parties that may be interested in the proposed CLC technology.

DemoCLOCK is looking for launching customers that are willing to work on a pilot scale to cover the gap in time and size between 500 kW and full scale power plant, and demonstrate progressively the scalability of the unit into industrial processes (power plant, refineries, etc.)

To facilitate the commercialization of the PBR-CLC technology, Array will study a business plan that takes the ever-changing business market into account. The Consortium will monitor DemoCLOCK's technology for its agility in the market and will evaluate the requirements needed to support the initial investment of staff time, funds and resources required to carry out the up-scaling of the technology measured against the projected long-term business benefits. This will lead to a reliable financial analysis, which can be used as a base for cost estimate for a new PBR-CLC full-scale project.

At the end of the project Foster Wheeler Italiana and POLIMI will prepare and publish a feasibility study for a full scale CLC plant that will include the main technical features, the environmental and the risk assessment for market entry of the novel technology with respect to the requirements of a pre-selected industrial plant types. The study will preliminary allocate the full-scale CLC power plant in the energy market, considering the variation of feedstock cost, electric power price, emission credit cost and financial aspects. This study will provide to the parties interested in the CLC technology a performance summary of a packed bed CLC-based power plant and a critical techno-economic evaluation, as well as a comparison with alternative benchmark CCS technologies.

More information can be obtained by contacting the project coordinator

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Cover picture: Puertollano IGCC Plant. Photo: Elcogas