1. PUBLISHABLE SUMMARY

Summary of the context and overall objectives of the project (For the final period, include the conclusions of the action)

CO_2 generation is an inherent part of cement production due to the calcination of limestone ($CaCO_3$ converted to CaO and CO_2). There are currently no feasible methods to produce clinker, and thus cement, without releasing CO_2 from $CaCO_3$. Furthermore, cement plants typically have a lifetime as long as 30-50 years. Altogether, the most viable option to reduce significantly greenhouse gas emissions from the cement industry is retrofit of CO_2 capture to existing cement plants. Most of the existing/envisaged CO_2 capture technologies have been developed for power plants, and will need targeted development to be retrofittable to cement plants. When considered for the cement sector, capture technologies are, at the startup of CEMCAP, typically at Technology Readiness Level (TRL) 4-5 or lower, with the exception of the amine technology demonstrated on-site (TRL8) at the plant of CEMCAP partner Norcem.

The primary objective of CEMCAP is to prepare the ground for large-scale implementation of CO_2 capture in the European cement industry. The project has been developed for broadening the portfolio of CO_2 capture technologies for the cement industry and bringing them to a higher TRL level and thus closer to deployment.

To achieve its primary objective, CEMCAP will
• Leverage to TRL 6 for cement plants the oxyfuel capture technology and three fundamentally different post combustion capture technologies (chilled ammonia process, membrane-assisted CO_2 liquefaction, calcium looping capture), all of them with a targeted capture rate of 90%.
• Identify the CO_2 capture technologies with the greatest potential to be retrofitted to existing cement plants in a cost- and resource-effective manner, maintaining product quality and environmental compatibility.
• Formulate a techno-economic decision-basis for CO_2 capture implementation in the cement industry, where the current uncertainty regarding CO_2 capture cost is reduced by at least 50%.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far (For the final period please include an overview of the results and their exploitation and dissemination)

After 12 months, CEMCAP has progressed to reach the achievements that were planned so far. A Framework document has been established to provide a common knowledge basis about cement plant operation and to provide input data for experimental and analytical research. The Framework describes a reference cement plant, the four capture technologies to be investigated and a reference capture technology (MEA). It specifies process units and utilities, CO_2 capture rate and purity as well as economic parameters and relevant key performance indicators. This will enable a consistent comparative techno-economic analysis later on in the project.

Based on the Framework, the following modelling and simulations have been undertaken:
• A reference cement plant to serve as basis for future capture technology integration studies.
• A full oxyfuel cement plant for future evaluation of experimental results from the oxyfuel burner, calciner and clinker cooler.

• The full-scale chilled ammonia process (CAP) system. For this purpose, a new rate-based model that includes a robust thermodynamic assessment of solid formation was developed. Simulations and optimization was undertaken for the full-scale CAP plant.
• Iterative simulations between a single-stage membrane unit and a CO2 liquefaction process, in order to determine optimum operational parameters under cement plant conditions.
• For calcium looping, the development of a one-dimensional entrained flow carbonator model is close to completion.
For all capture technology process simulations, model parameters will be updated as results become available from the experimental activities in CEMCAP.
Furthermore, an economic analysis of the reference cement plant without CO2 capture has been performed to provide a basis for the future techno-economic comparison of technologies.

Experimental research is in CEMCAP carried out for three oxyfuel cement plant components (burner, calciner and clinker cooler) and for three different post-combustion capture technologies (Chilled ammonia, membrane-assisted CO2 liquefaction and calcium looping). Experimental plans, aligned with the CEMCAP Framework document, have been developed for all test to be undertaken.
Progress in the testing of oxyfuel technology for cement plants:
• A 500 kWth burner test facility is being adapted for cement-plant relevant oxyfuel burner testing. (First tests scheduled in July 2016). A prototype burner, based on a downscaled industrial burner, has been designed and manufactured. A CFD model developed for oxy-fuel combustion has been validated against reference oxyfuel experimental data and will be used for analysis and upscaling of the new burner.
• An electrically heated 50 kW entrained flow reactor test facility has been modified for oxyfuel calcination tests, and the experimental investigation of entrained flow calcination has started.
• An oxyfuel clinker cooler prototype has been designed and manufactured for installation at the HeidelbergCement plant in Hannover in summer 2016. Because a concept was chosen which includes the extraction of hot clinker from a running production line, an advanced extraction system had to be invented.

Progress in the testing and development of post-combustion capture technologies for cement plants:
• For the pilot-scale testing of the chilled ammonia process (CAP), an existing pilot plant (1 tonne CO2/day) was adapted for CEMCAP conditions, and the first absorber experimental campaign was successfully executed.
• A setup for CO2 membrane performance testing has been assembled, and the work on identifying promising membrane material types is in progress. The total flow of the CO2/N2 mixture that can be supplied is 1000 ml/min.
• For calcium looping, a 200 kWth pilot was modified to match the requirements of the CEMCAP framework, after which two test campaigns were conducted. Stable calcium looping operation with CO2 capture rates above 95% was reached using high limestone make up flows and a synthetically mixed flue gas. A 30 kW rig was refurbished in order to operate under conditions relevant for cement plants, and experimental campaigns were conducted, investigating the influence of various process parameters upon CO2 capture rate. Also in this ring, various raw materials for cement production were tested and analysed.

CO2 geological storage and CO2 utilisation are the two routes to handle CO2 after capture. A report on the status and knowledge of these options is currently in progress. The point of view of the cement industry is adapted, and the work is relying on the CEMCAP Framework.

The CEMCAP website has been launched, CEMCAP is on twitter (@cemcap_co2) and the project has published two newsletters and three blogs. The first out of three joint CEMCAP/ECRA workshops was arranged with focus on knowledge transfer between the partners and to the ECRA CCS steering committee.

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

All the experimental research in CEMCAP is progressing CO2 capture from cement plants beyond state of the art, towards results were it will be possible to say that the CEMCAP technologies have been demonstrated in an industrially relevant environment (TRL6).

The oxyfuel pilot-scale clinker cooler is unprecedented in its innovative design, just as the oxyfuel burner adaptations and the new oxyfuel nozzle design are unprecedented. Calcination is tested in a CO2 rich-environment relevant for oxyfuel, and calcium looping tests with a high substitution rate of CO2 absorber has not been tested before. A chilled ammonia absorber has never before been tested for such high CO2 concentrations (up till 35%).

Furthermore, the CEMCAP Framework provides an unprecedented assembly of knowledge and data for simulations of CO2 capture from cement plants. This includes how to take into account the varying false air ingress, which leads to varying exhaust gas flowrates and CO2 concentrations, even for a cement plant operating at steady state. When made public in 2017, and thoroughly promoted by CEMCAP, the framework will provide background for other projects to undertake CO2 capture studies that can deliver results comparable to CEMCAP results.

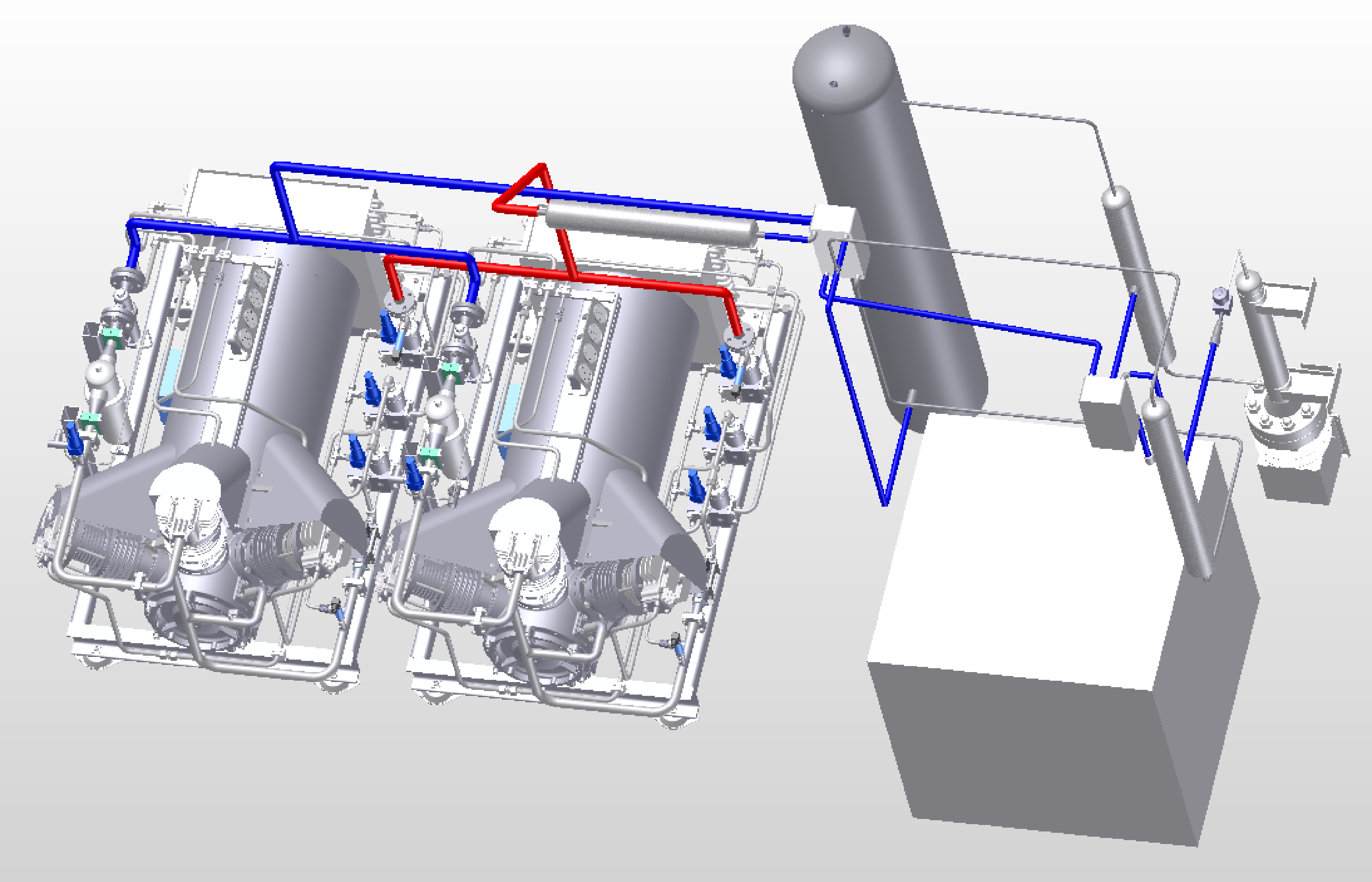
Knowledge sharing is essential for the progress and impact of CEMCAP. Industrial and research partners with backgrounds in cement and in CO2 capture from power plants have met during the first CEMCAP/ECRA workshop, the project-internal technical meetings and also interact continuously through the ongoing research.

Altogether, the CEMCAP project is progressing towards identifying the most cost- and resource effective options for CCS in the cement industry, and hence in a longer perspective towards expanding the options for CCS deployment in Europe.

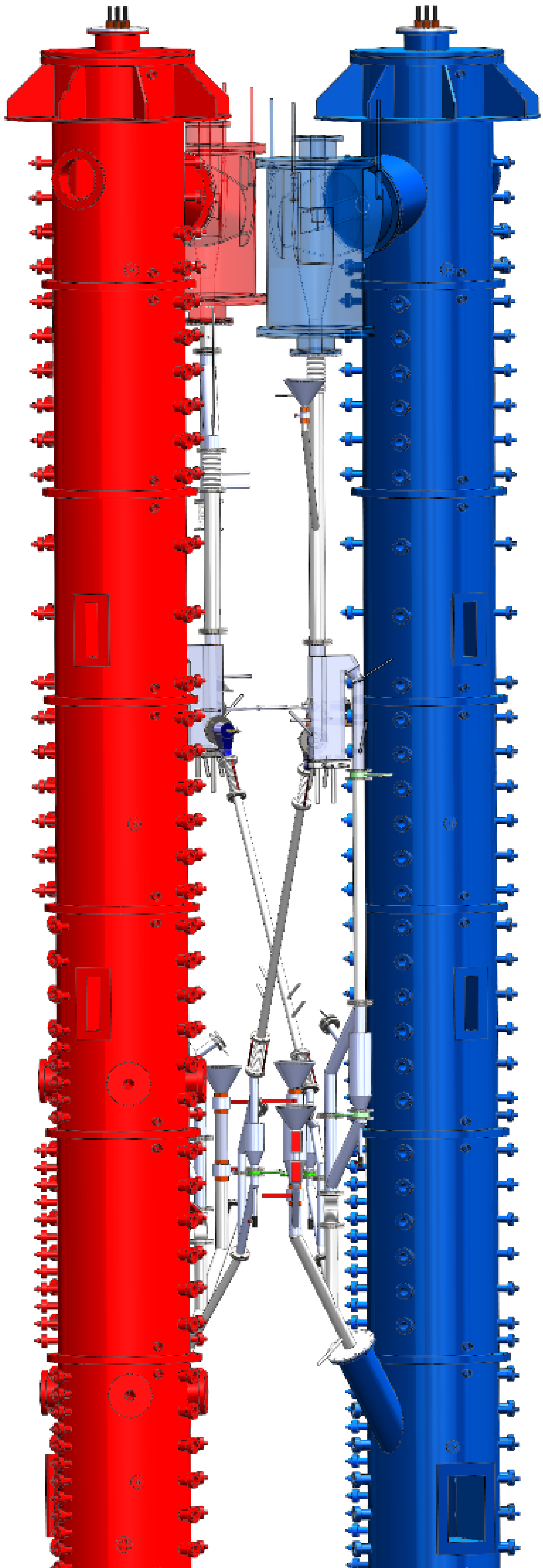
Address (URL) of the project's public website

http://www.sintef.no/cemcap/

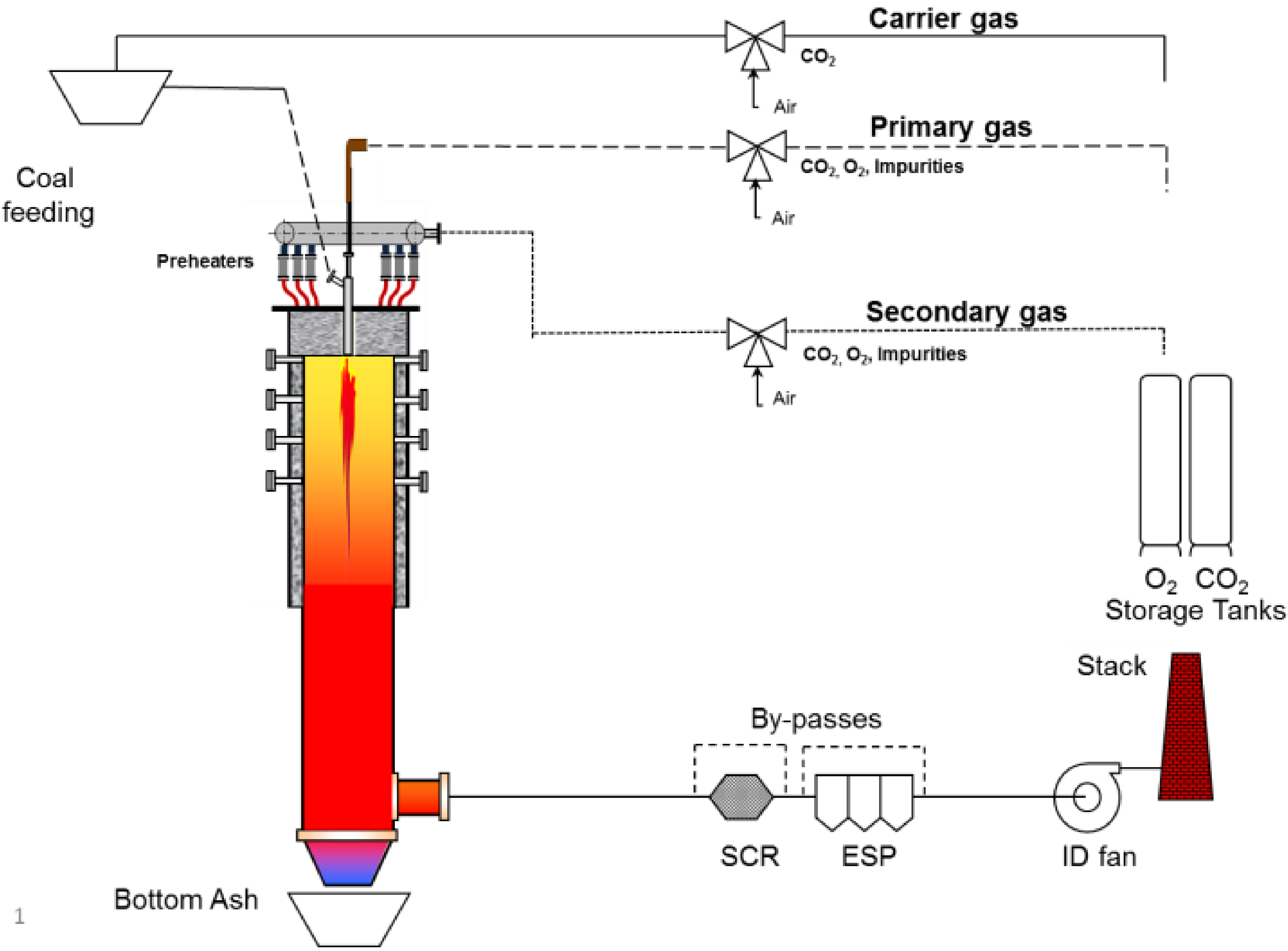
The test rig for CO2 liquefaction (SINTEF-ER)



The USTUTT/IFK 200 kWth Calcium looping test rig



The USTUTT/IFK 500 kWth oxyfuel test rig



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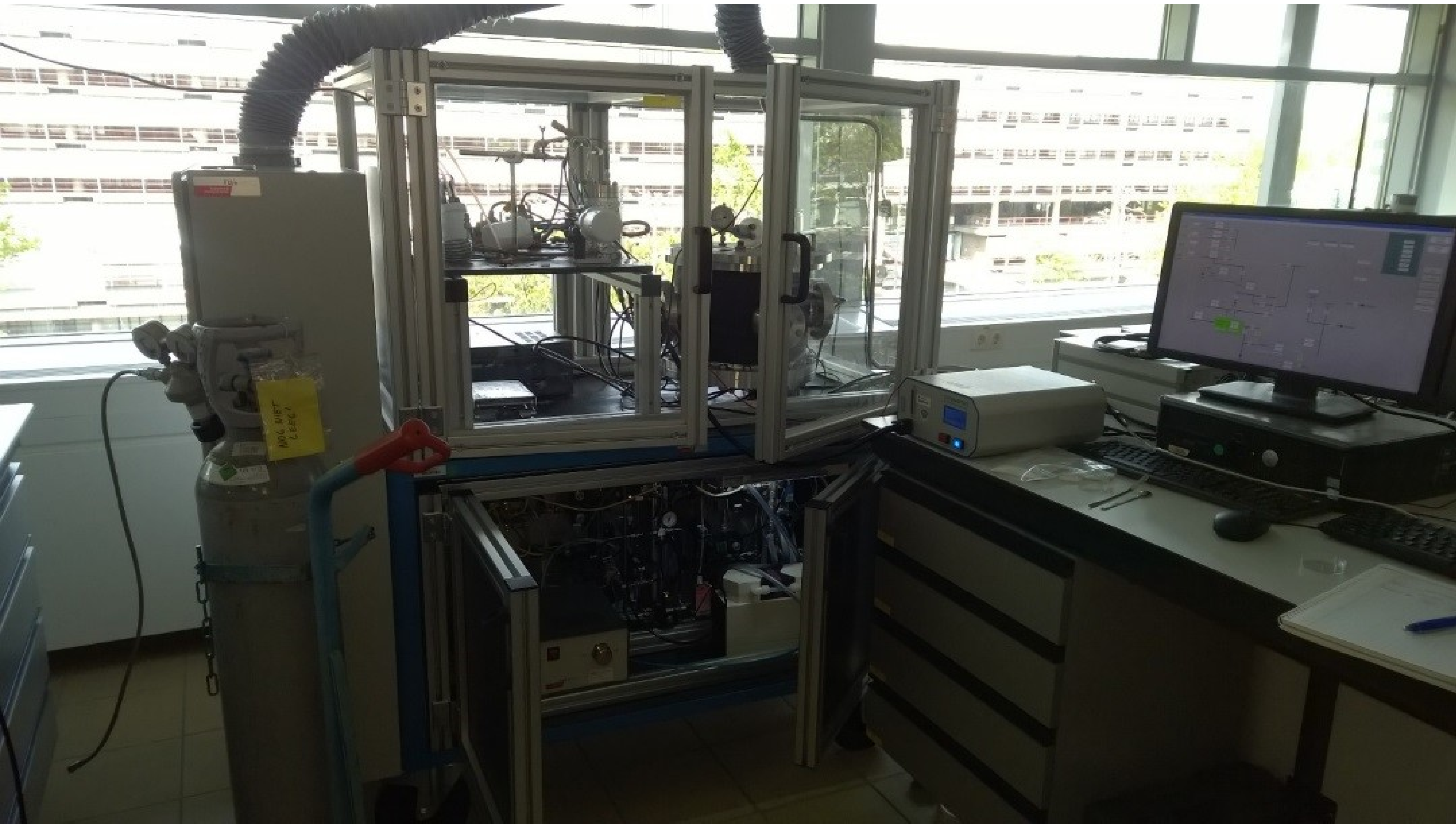
Overview of the CSIC 30 kWth Ca looping plant

Visit to the HeidelbergCement plant in Lixhe, BE

Facility for membrane testing at TNO



Hot clinker extraction point for oxyfuel clinker cooler (IKN)

The chilled ammonia plant at GE Power Sweden