1. PUBLISHABLE SUMMARY

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

CO2 generation is an inherent consequence of cement production due to the calcination of limestone (CaCO3 converted to CaO and CO2). There are no alternative methods to produce clinker, and thus cement, without releasing CO2 from CaCO3. Furthermore, cement demand has been growing continuously since the beginning of last century. Altogether, the most viable option to reduce significantly greenhouse gas emissions from the cement industry is to retrofit CO2 capture to existing cement plants. Most of the existing/envisaged CO2 capture technologies have been developed for power plants, and will need targeted development to enable retrofitting of cement plants. When considered for the cement sector, capture technologies were, 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 CO2 capture in the European cement industry. The project has been developed for broadening the portfolio of CO2 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 TRL6 for cement plants the oxyfuel clinker cooler, calciner, and burner, and three fundamentally different post combustion capture technologies (chilled ammonia process (CAP), membrane-assisted CO2 liquefaction, calcium looping (CaL) capture).
• Identify the CO2 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 CO2 capture implementation in the cement industry, where the current uncertainty regarding CO2 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)

A framework document has been published on the CEMCAP website that provides a common knowledge basis about cement plant operation and provides input data for experimental and analytical research. This will enable a consistent comparative techno-economic analysis.

Based on the framework, the following modelling and simulation work was performed:
• A reference cement plant was simulated to serve as basis for future capture technology integration studies.
• A cement plant with MEA CO2 capture was simulated, and will serve as a reference for the techno-economic evaluation of the CEMCAP technologies.
• A model of a full oxyfuel cement plant with oxyfuel burner, calciner and clinker cooler was developed.

• Extensive simulations, including heuristic parameter optimization of a full-scale CAP system, were performed in order to find a set of operating conditions that minimizes the CAP energy consumption.
• Process simulations for membrane-assisted CO2 liquefaction were performed to establish capture-process data, preparing for pilot-scale testing.
• Process simulations of two CaL process integration options (tail-end CaL and highly integrated CaL) were performed, supported by fluidized-bed and entrained-flow carbonator models.

For all capture technology process models, model parameters will be updated as results become available from the experimental activities in CEMCAP. This work is in progress for both the oxyfuel components, CAP, membrane-assisted CO2 liquefaction and CaL technology.

Economic analyses of the reference cement plant without and with MEA CO2 capture were performed to provide a basis for the future techno-economic comparison of technologies, and methodologies for cost estimation of non-standard process components were established. First process integrations of the CEMCAP technologies in the reference cement plant were done and preliminary energy-related key performance indicators (KPIs) were calculated.

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).

The progress in testing and experiments of oxyfuel technologies for cement plants is after two years:
• Two experimental campaigns have been conducted in a 500 kWth burner test facility with petcoke as fuel. A third experimental campaign is planned, for a different fuel.
• Calcination experiments have been conducted in a 50 kW electrically heated entrained flow reactor facility for both air and oxyfuel scenarios. Tests have been carried out for different reactor temperatures and residence times, and additional tests are in progress.
• An oxyfuel clinker cooler prototype was installed at the HeidelbergCement plant in Hannover. The prototype was tested in several campaigns over a period of 6 months.

Progress in the testing and development of post-combustion capture technologies for cement plants is:
• Pilot-plant tests of a CAP CO2 absorber without fluegas impurities and the direct contact cooler were concluded.
• A setup for CO2 membrane performance testing was assembled, and a set of suitable membranes for the capture process was acquired.
• A wide range of CaL operation parameters were screened in a 30 kW CaL test facility. One experimental campaign was carried out in a 200 kW pilot facility, while a second campaign is planned.

A report on the status and knowledge of different routes for post capture CO2 management, where the point of view of the cement industry is adopted, is in progress. The following five routes are selected for techno-economic evaluation: (i) Mineralization to MgCO3, (ii) geological sequestration, (iii) CO2 hydrogenation to ethanol, (iv) CO2 polymerization to polypropylene carbonate, and (v) food-grade CO2.

The CEMCAP website is continuously updated with news, presentations and results from the consortium. CEMCAP is active on twitter (@cemcap_co2) with 157 tweets so far, and the project has published four newsletters and blog posts, respectively. The first out of three joint CEMCAP/ ECRA workshops has been arranged with focus on knowledge transfer between the partners and to the ECRA CCS steering committee.

Progress beyond the state of the art, expected results until the end of the project and 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, with demonstrations in industrially relevant environments (TRL6).

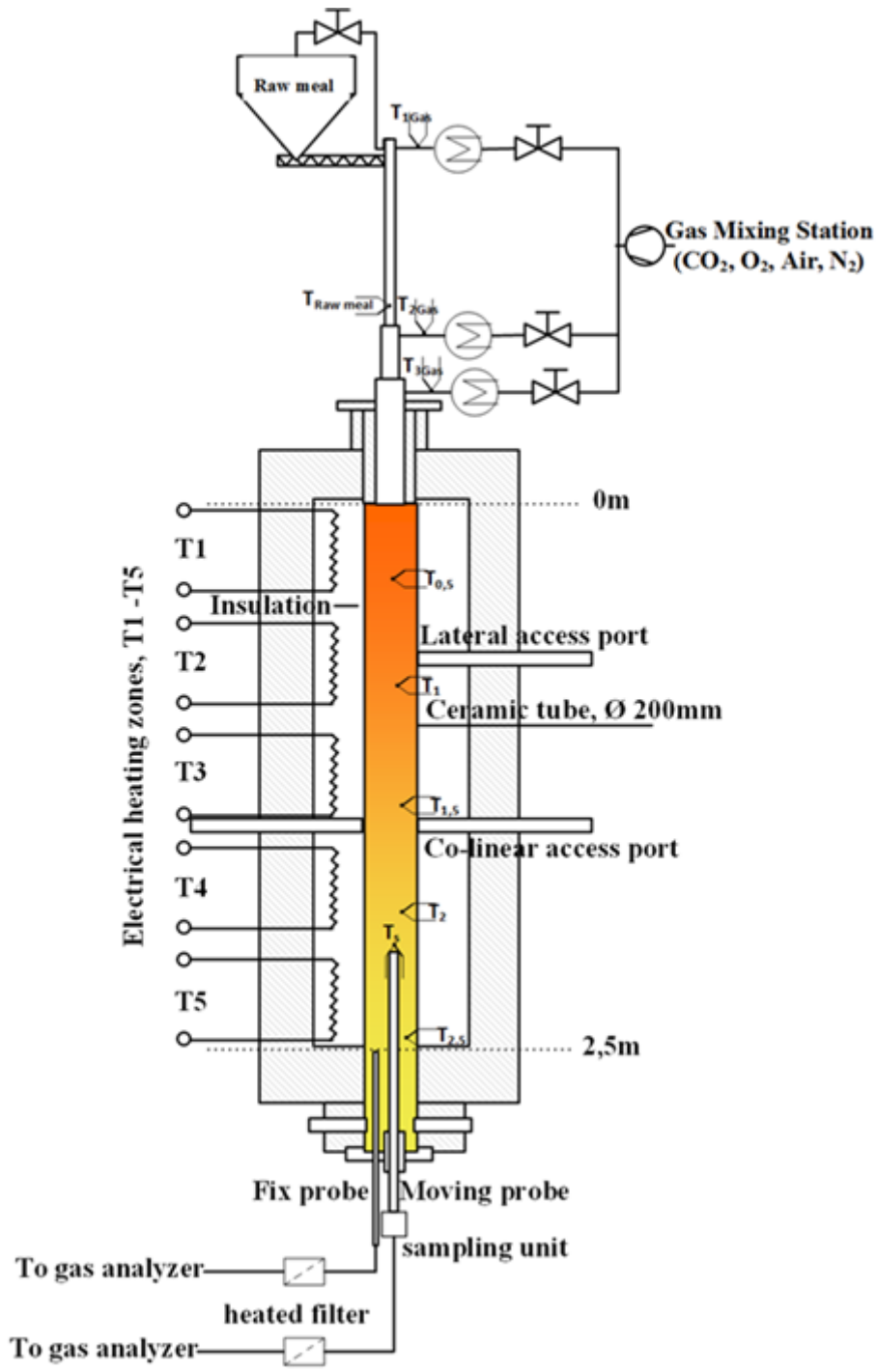
The oxyfuel pilot-scale clinker cooler is unprecedented in its innovative design, just as the oxyfuel burner adaptations and the new oxyfuel nozzle design are unprecedented. Calcination is tested in a CO2 rich-environment relevant for oxyfuel, and CaL with a high substitution rate of CO2 absorber has not been tested before. CAP technology has never before been tested for such high CO2 concentrations (up to 35%). Furthermore, the CEMCAP framework provides an unprecedented assembly of knowledge and data for simulations of CO2 capture from cement plants.

To summarize, CEMCAP is progressing towards identifying the most cost- and resource effective options for CCS in the cement industry thereby expanding the options for CCS deployment in Europe.

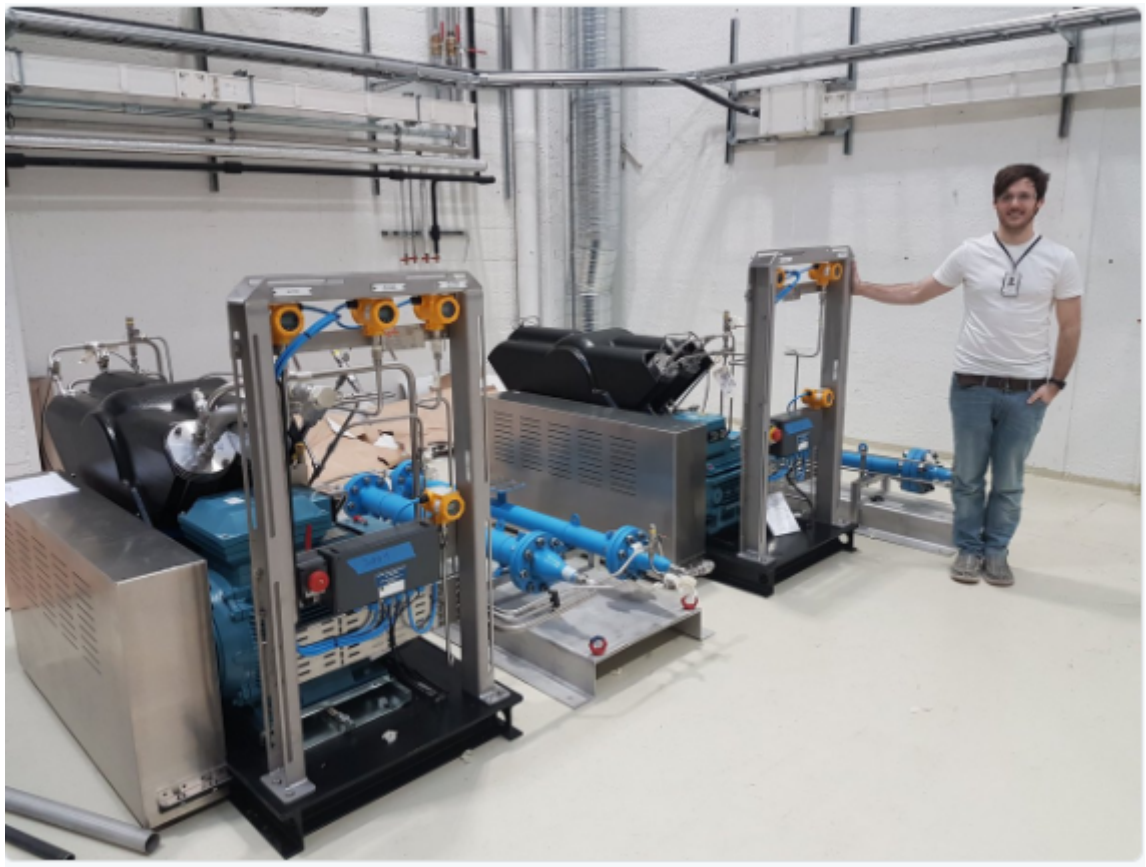
Address (URL) of the project's public website

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

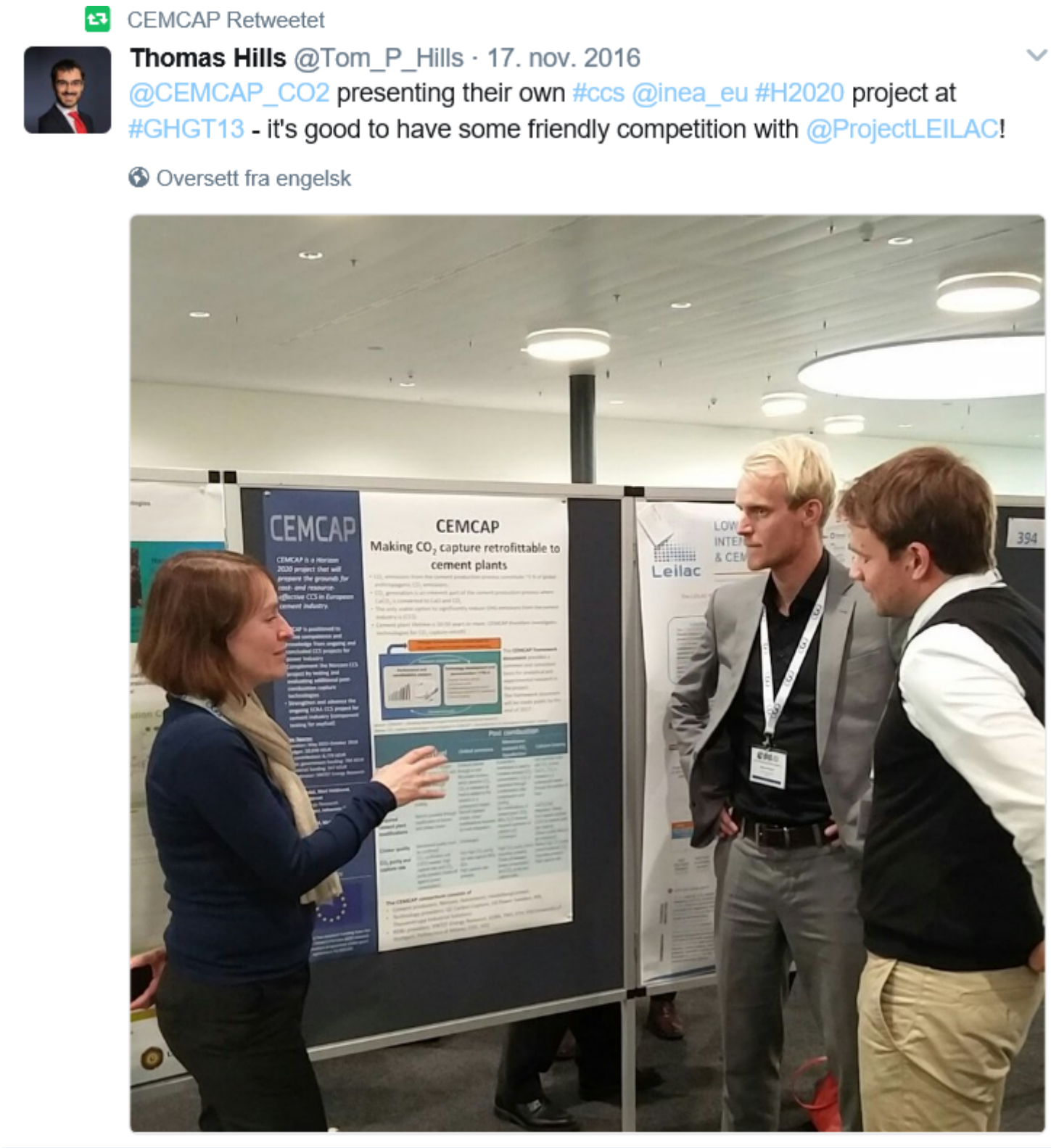
Experimental facility at IFK, University of Stuttgart, for entrained calciner tests.



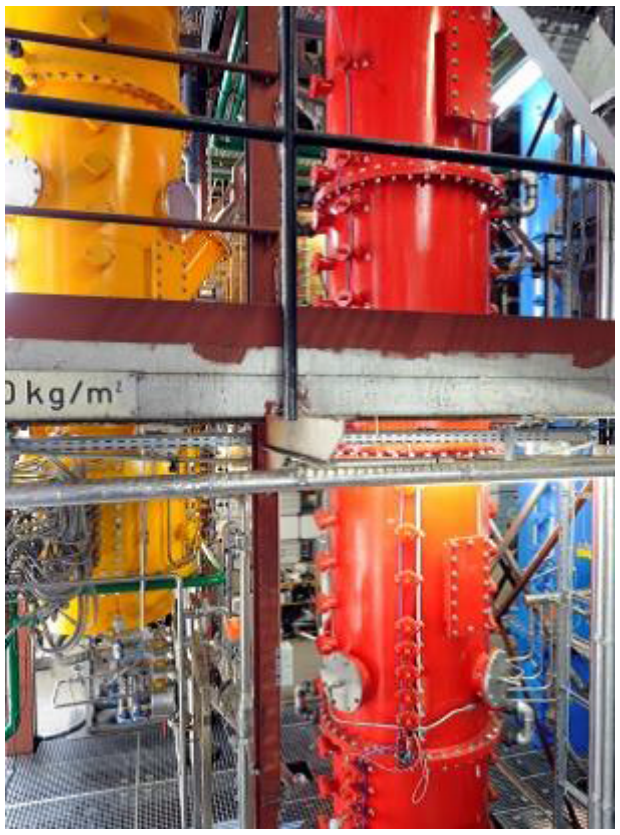
Preparing the rig for experiments of membrane-assisted CO2 liquefaction.



CEMCAP present at GHGT13 in Lausanne to disseminate results on CO2 capture from cement plants.



Calcium looping pilot plant at IFK (University of Stuttgart).



Oxyfuel clinker cooler pilot plant.

Experimental rig used for the Direct Contact Cooler (DCC) tests carried out by GE Power Sweden.

An oxyfuel burner