Negative CO_2

Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

Newsletter #5
December 2018

This is the fifth edition of the newsletter of The Nordic Energy Research Flagship Project "**Negative CO_2 Emissions with Chemical Looping Combustion of Biomass**". This edition covers the results and progress of the project in the period from June 2018 to December 2018.

The objective of this project is to demonstrate an effective pathway that produces energy while actively reducing the level of CO_2 in the atmosphere. The usage of sustainable biomass in the process called chemical-looping combustion (bio-CLC) is highly efficient and facilitates a more convenient capture of the biogenic CO_2. The permanent geological storage of this CO_2 reduces the level of CO_2 in the atmosphere. For a more detailed explanation of bio-CLC, click here.

Haven't heard about CO_2 capture and storage before? Click here for an introduction.

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About Negative CO_2

Negative CO_2 is a multi-partner and cross-disciplinary project funded by Nordic Energy Research that runs from November 2015 to October 2019. The research topic is CO_2 capture during biomass combustion by means of an innovative and potentially revolutionary technology. The project partners are:

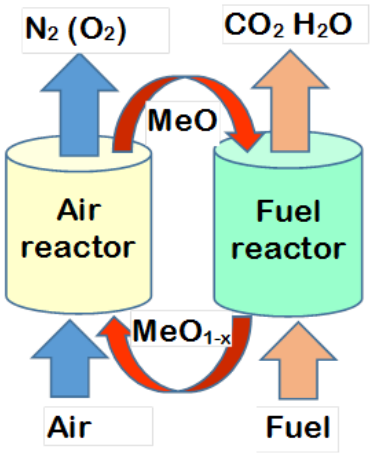
- Chalmers University of Technology
- The Bellona Foundation
- Sibelco Nordic AB
- SINTEF Energy Research
- SINTEF Materials and Chemistry
- VTT Technical Research Centre of Finland Ltd
- Åbo Akademi University

Associated with the project is also an advisory board, consisting of various stakeholders with interest in the project:

- Alstom Power AB
- Andritz Oy
- AKZO Nobel
- Elkem AS
- E.ON Sverige AB
- Fortum Oyj
- Sumitomo SHI FW
- Göteborgs Energi
- Titania A/S
- Arbaflame A/S
- Fores

The Challenge: remove CO_2 from the atmosphere

This project combines technologies and research that will be help us reduce the level of CO_2 in the atmosphere effectively and at a low cost. To achieve the climate goals of the *Paris Climate Agreement*, we need to effectively stop any and all emissions of CO_2 where possible, and compensate for emissions we cannot avoid (for instance from agriculture).



Chemical-Looping Combustion

According to the UN Intergovernmental Panel on Climate Change (IPCC), the necessary measures include: the uptake of renewable energy, electrification, and Carbon Capture and Storage (CCS). These solutions alone will, however, not be enough. We need to decrease the amount of CO_2 that is already present in the atmosphere. We need large-scale negative emissions.

In the Nordic countries, there is a large potential for the capture and permanent geological storage of CO_2 from biomass. Norway has 20 years of experience in full-scale CO_2 storage, and is planning for a large-scale CO_2 transport and storage infrastructure ready by 2022 that could receive CO_2 northern and Western Europe. Sweden and Finland have large point source emissions of CO_2 from biomass.

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Chemical Looping Combustion

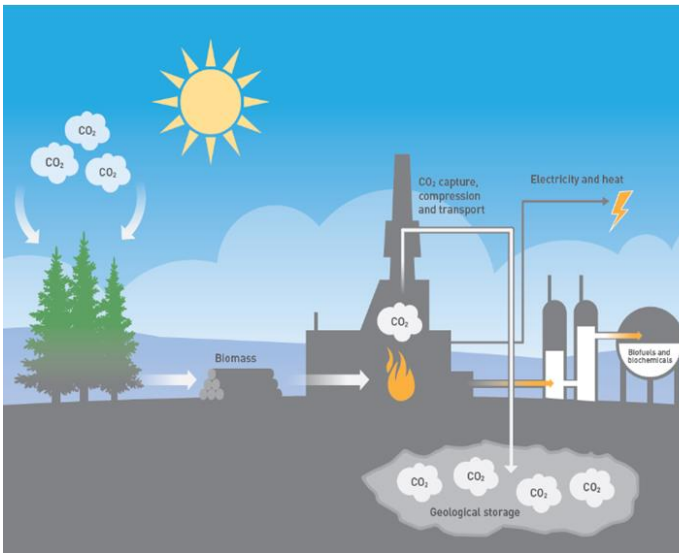
Chemical Looping Combustion (CLC) is a technology able to capture CO_2 from energy production at relatively low cost and with high efficiency. Conventional combustors burn fuel with ambient air, which contains the needed oxygen as well as a lot of nitrogen, and this makes separating the CO_2 after combustion a complex and expensive process. CLC installations solve the nitrogen problem by burning fuel with solid metal oxide particles that create an oxygen-rich, nitrogen-free combustion atmosphere within the system.

When the fuel reacts with these particles, which are called the oxygen carrier, the oxygen is transferred to the fuel giving the same combustion products as normal combustion. These are CO_2 and water vapor. The important difference is that the combustion products leave the so-called fuel reactor without any of the nitrogen in the air, and when the gas is cooled, the water vapor condenses resulting in an essentially pure CO_2 stream.

And, this is the important point, this can be done without any costly and energy demanding gas separation. The oxygen carrier is easily regenerated in an air reactor where the oxygen in the air is taken up by the oxygen carrier. Thus, oxygen is transported to the fuel reactor by oxygen-carrying particles that travel between a fuel reactor and an oxygen reactor in a steady loop. For oxygen carrier, low-cost natural minerals like ilmenite and manganese or iron ores can be used, and these materials can circulate between the two reactors for hundreds of hours. Because the costly gas separation can be avoided CLC is expected to reduce the cost of CO_2 capture dramatically.

Biomass and CLC

The usage of sustainable biomass as the fuel in this process allows for the efficient withdrawal of CO_2 from the atmosphere. Biomass binds carbon as it grows, thus taking CO_2 (carbon dioxide) from the atmosphere. When the biomass is used in energy production, the CO_2 is recreated and returned to the atmosphere. But, if the CO_2 is instead captured and subsequently stored underground, that CO_2 will never end up back in the atmosphere again. This means that CO_2 removed from the atmosphere by the biomass as it grew, is permanently removed from the atmosphere. The result is negative CO_2 emissions (see fig. 2).



Electricity and biofuels production with Bio-CCS (Illustration by doghouse.no/sintef)

Bio-Energy and CCS (BECCS) or Bio-CCS.

The use of sustainable biomass in combination with CLC (Bio-CLC) will achieve negative emissions efficiently, while providing energy simultaneously. The aim of the project is to take the technology to the next level in its development by upscaling it to a semi-commercial scale.

Highlighted results in brief

Since June 2018, there has been very high activity regarding publication, profiling and dissemination.

Project representatives presented at four important conferences in this period.

The 14th bi-annual Greenhouse Gas Technology was held in Melbourne, Australia, October 22-25th. This project presented a total of 5 technical articles in the oral sessions. In addition, 2 posters based on our project were displayed.

The University of Utah hosted the 5th International Conference on Chemical Looping, in Park City, Utah 24-27 September 2018. Results from our project were highlighted in several presentations during this conference. About 150 participants were gathered for more than three full days of presentations, posters, pilot units visit, and networking and social activities.

Chalmers, VTT and SINTEF were present with several persons, giving both key notes speeches (Anders Lyngfelt), as well as oral and poster presentations from the work in the Negative CO_2 project. It is worth mentioning that Chalmers, VTT and SINTEF (Anders Lyngfelt, Toni Pikkarainen and Øyvind Langørgen) were all members of the scientific committee of this conference.

Our project partners VTT and Åbo Akademi presented at the Liekkipäivät, also known as The Finnish Flame Days, organised by The Finnish National Committee of the IFRF, International Flame Research Foundation. The conference was held on October 23rd in Espoo, Finland. This brought together various national experts, boiler manufacturers, end-users and commercial players in Finland, all having a direct interest in new boiler and power conversion technologies.

On September 7-9th, Åbo Akademi presented at the PSN 2018, Krakow, Poland, Polish- Scandinavian-Nordic section joint meeting Krakow. The Negative CO_2 project was presented with special highlights from the work on corrosion performed at Åbo Akademi under WP5.

Research activity within the work packages of the flagship project has been high in this period.

In September 2018, a second biomass test campaign was performed in the 150 kW CLC pilot unit at SINTEF ER, following up on the first such test performed in Q4 2017.

In June 2018 a test campaign was successfully completed in the Chalmers 100 kW CLC pilot. The campaign involved three major breakthroughs in the research and development of Bio-CLC:

1. The use of a manufactured, high-performance oxygen carrier, calcium manganite in CLC with high volatile biomass, showing extraordinary high performance.
2. On-line measurements of alkali.
3. Use of fuels with extraordinary high alkali content, e.g. straw pellets.

More detailed highlights on these and other activities within each work package are given below.

WP2 Pilot Plant Operation

The work in WP2 aims to increase the scale of Bio-CLC operations to demonstrate the commercial and technical feasibility of the technology. This will bring it closer to industrial application. Earlier, a very few studies on continuous CLC operation with biomass has been reported in literature, and for these, the fuel power has been limited. The Negative CO_2 project has access to unique infrastructure for performing CLC experiments with biomass under realistic conditions. Three pilot units are available, at VTT, Chalmers and SINTEF, with a design size ranging from 50–150 kW_{th}. In addition, a semi-commercial CFB boiler located at Chalmers has been used to demonstrate Bio-CLC at larger scale (1–4 MW_{th}) and conditions truly relevant for industrial applications. This scale of operation is far larger than what we have been able to find from literature.

All the units are based on fluidized bed technology, but they have some differences in design. All have been successfully operated in the course of the project. Thus, we have now the proof-of-concept, and the experiences expected and needed in the project. Together they provide real data on the performance of Bio-CLC depending on factors as reactor design, choice of oxygen carrier and choice of fuel and fuel preparation.

The 5th International Conference on Chemical Looping was arranged on September 24-27 in Salt Lake City and Park City in Utah. About 150 participants were gathered for more than three full days of presentations, posters, pilot units visit, and networking and social activities.

Chalmers, VTT and SINTEF were present with several persons, giving both key notes speak (Anders Lyngfelt), as well as oral and poster presentations from the work in the Negative CO2 project. It is worth mentioning that Chalmers, VTT and SINTEF (Anders Lyngfelt, Toni Pikkarainen and Øyvind Langørgen) were all members of the scientific committee of this conference.

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New successful operation with biomass fuel in the 150 kW CLC pilot unit at SINTEF Energy Research (WP2)

In September 2018, a new test campaign was performed in the 150 kW CLC pilot unit at SINTEF ER, using biomass pellets as fuel. The biomass feed was whole "black-wood" pellets, i.e. steam exploded wood pellets provided by Arbaflame AS. The oxygen carrier was ilmenite from Titania AS.

The main achievements of this test are summarized here.

Stable biomass feed-rate of 100 – 105 kWth was obtained.

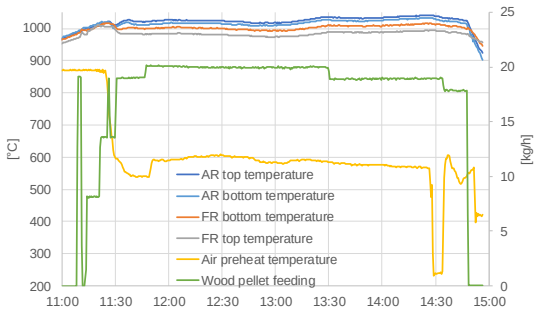
To our knowledge, only the operation in the semi-commercial CFB unit at Chalmers (also part of the Negative CO2 project) has obtained larger biomass feed-rates in CLC mode.

Nearly auto-thermal operation was designed for and observed.

The only additional heat was pre-heating of the primary air to the air reactor to about 550 - 600 °C. Achieving auto-thermal operation has been seen as one of the main issues for the CLC process so this result on a 100 kW scale gives further proof to the feasibility of the process.

Stable temperatures in the air reactor of about 1030 °C was achieved, whereas bottom part of fuel reactor maintained about 1000 °C.

Oxygen demand down to about 15 – 17 % was achieved with a CO_2 capture rate and fuel conversion of 85 %.



Temperatures and fuel feed rate during pellets test at the SINTEF ER 150kWth plant in September, 2018. AR= Air Reactor FR=Fuel Reactor

From control room during the test September 2018.

New successful operation with biomass fuel in the 100 kW CLC pilot unit at Chalmers University of Technology (WP2)

In June 2018 a test campaign was successfully completed in the Chalmers 100 kW CLC pilot. The campaign involved three major breakthroughs in the research and development of Bio-CLC:

1. The use of a manufactured, high-performance oxygen carrier, calcium manganite in CLC with high volatile biomass, showing extraordinary high performance.
2. On-line measurements of alkali.
3. Use of fuels with extraordinary high alkali content, e.g. straw pellets.

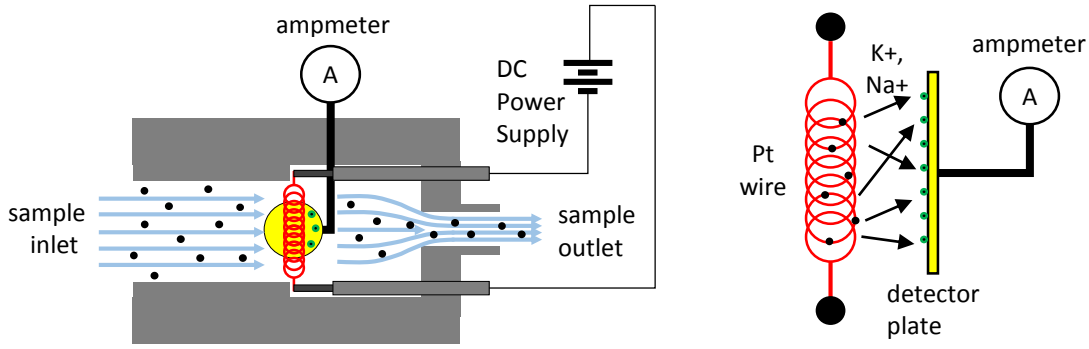
The first breakthrough is quite interesting for several reasons. Firstly, the calcium manganite lowered the fraction of unburned gases from the fuel reactor by a factor of approximately ten, which in turn corresponds to a similar reduction in the need for oxygen to process gas downstream. Secondly, calcium manganite has previously not been considered for use with solid fuels because it is sensitive to the high concentrations of sulphur typical of coal (which had high focus in CLC development at that time), although it has been successfully used with natural gas in a number of pilots in Europe, showing not only high performance but also high durability. With biomass fuel, sulphur is not a problem. Thirdly, calcium manganite can be produced from low cost natural minerals, i.e. limestone and manganese ore. Lastly, it should be said that calcium manganite is what is called a CLOU material. CLOU means Chemical-Looping with Oxygen Uncoupling, and this signifies a variety of chemical-looping combustion where the oxygen carrier is not only able to react with fuel gases in the fuel reactor, but actually releases oxygen. Therefore, CLOU materials can reach very high performance, and previous results with natural gas clearly shows that full gas conversion can be reached.

The second breakthrough provides us with a tool for understanding how different oxygen carriers interact with alkali containing fuels. Of particular interest to note that the measurements indicated that only a few percent of the alkali coming in with the fuel was leaving the system with the exiting flue gas. This, in turn, indicated that the alkali was taken up by the oxygen-carrier bed material. That a majority of the alkali was also absorbed in the bed material was later confirmed by elementary analysis of several samples of bed material. It should be said that the calcium manganite was diluted with another oxygen carrier, ilmenite, because there was not enough of calcium manganite. Whether the alkali was taken up by the ilmenite only, or by both ilmenite and calcium manganite, is not known at present.

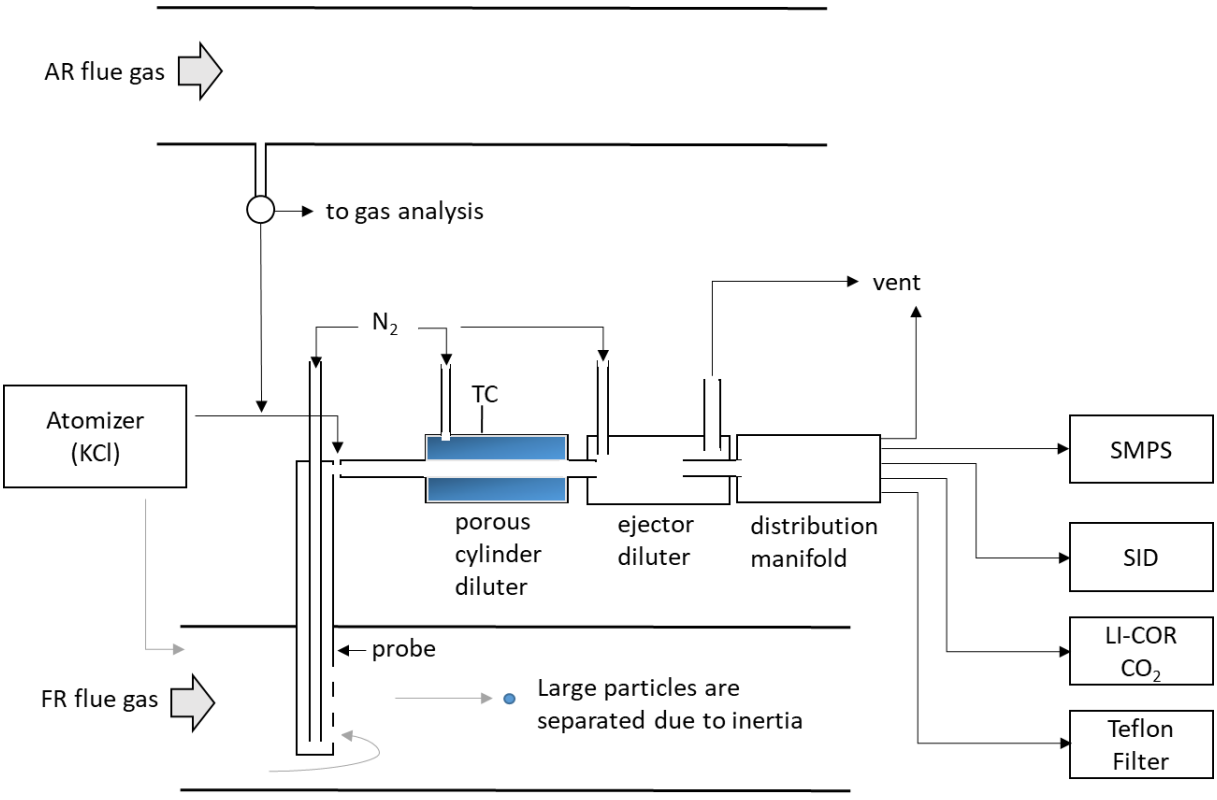
The third breakthrough, although involving only a few hours of actual operation, is the use of high alkali fuels. Two fuels with an alkali content 24-26 times higher than the reference biomass fuel were used. One of these was accomplished by mixing in 50% crushed straw pellets in the reference fuel.

Chemical-looping combustion could potentially come with advantages with respect to the alkali in biomass fuels, both lowering costs for wood-based fuels but potentially also facilitating the use of

more difficult biomass fuels with very high alkali content like straw, which is commonly used in biomass combustion in Denmark. The 2nd and the 3rd breakthroughs are the basis for understanding of this aspect.



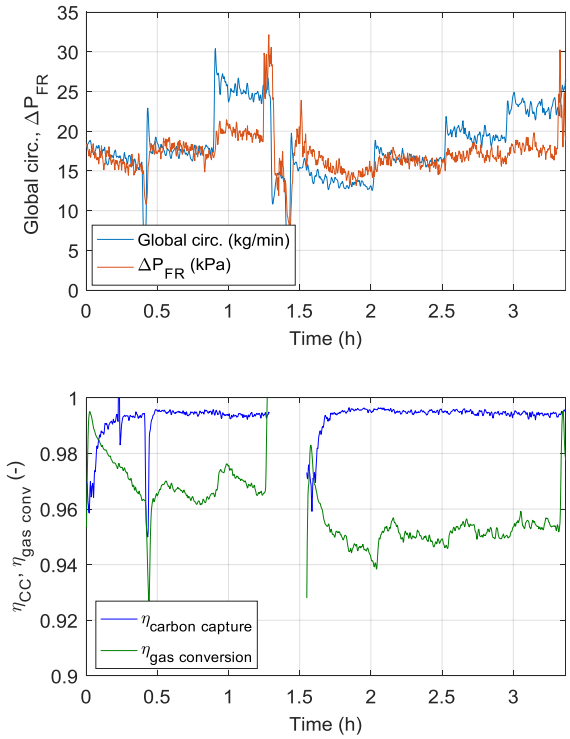
Surface Ionization Detector (SID) Simplified Diagram for alkali measurements



Alkali measurements: Sampling, Dilution, Calibration and Measurement System Diagram

Summary of CLC operation at Chalmers University in Q3 2018 showing time of fuel operation, fuel flow and corresponding fuel power. BP=black pellets, SP=straw pellets

Fuel	Time (h)	Fuel flow (kg/h)	Fuel power (kW)
BP	9.90	12.4-14.0	64-73
BP + K_2CO_3	2.10	11.1	57.5
BP + SP	2.40	7.3-9.7	34-45
Wood char	4.20	9.1-11.0	76-92



First day of operation, using black pellets as fuel. Top: global solids circulation, solids inventory in the fuel reactor. Bottom: carbon capture and gas conversion. The gap around t=1.5 h is due to pausing fuel feeding to add oxygen-carrier particles.

Note gas conversion around 97% first hour, falling to around 95% in the following hours, i.e. after dilution with more ilmenite at 1.5 h.

100 kW CLC Reactor Alkali Mass Balance (Chalmers U. Q3 testing) indicating that only a small fraction of the alkali added with the fuel is found in the flue gas.

Fuel	Circulation Rate	Alkali Input Rate (mg K+Na/min)	FR Flue Gas Alkali Release Rate (mg K/min)	AR Flue Gas Alkali Release Rate (mg K/min)	FR % Release	AR % Release	Bed % Retention
BP	Low	101	0.8	1.8	0.7%	1.8%	97.5%
	Medium	101	0.5	-	0.5%	-	-
	High	101	0.5	-	0.5%	-	-
BP+K_2CO_3	Low	2093	1.2	-	0.06%	-	-
	Medium	2093	1.7	-	0.08%	-	-
BP+SP	Medium	1173	9.9	9.6	0.8%	0.8%	98.3%
	High	1173	11.3	-	1.0%	-	-
Wood Char	Low	635	4.8	-	0.8%	-	-
	Medium	635	2.5	-	0.4%	-	-
	High	635	5.0	-	0.8%	-	-

These results have been presented at *5th International Conference on Chemical-Looping*, Sept 2018, and the conference paper is submitted for publication.

Meeting with Gassnova 29th of August

Jørild Svalestuen and Svein Gunnar Bekken from Gassnova visited SINTEF Energy Research in Trondheim on 29th of August. The purpose of the meeting was to get updated information about the CLC activity. The CLC activity within SINTEF was presented by Øyvind Langørgen with focus on the Negative CO2 project and the possibilities within the Nordic countries for establishing CLC as a high potential BECCS (Bio Energy with CCS) technology. Gassnova expressed interest in the developments and progress made, and for relevant pilot plans that may arise from a project such as Negative CO_2.

Exhaust gas analysis at test CLC plant at SINTEF ER

Visit from the CLIMIT board on 16th of October

The board of the CLIMIT programme of the Research Council of Norway (http://www.climit.no/en) and their guests visited the 150 kW_{th} CLC unit at SINTEF Energy Research on 16th of October. The CLIMIT programme board consists of members from industry, politics, organisations and universities and research institutes. The board members showed great interest in the technology and it generated a lot of questions and discussion. Because of this, the visit took much more time than planned. However, it is a clear conclusion that the visitors learned a lot more about CLC in such a forum than they have done earlier through general reports and presentations in seminar and conferences. Really great to have such interested visitors!

Upper part of reactors at operating temperature (1000 oC) during SINTEF ER CLC testing Q3 2018

Scenes from a research project visit: SINTEF ER hosts the CLIMIT board at their 150 kWth CLC plant in the Autumn of 2018. Øyvind Langørgen in the yellow jacket.

WP3 Oxygen carrier materials and WP4 Flue gas treatment

The ilmenite particles used in the test campaigns this period (described in the section for WP2 above) were sent to project members in WP3 for complete analysis after completion of the CLC tests. Early, unpublished results indicate that the particles were not coated with any deposit due to the CLC operations. However, the reasons for the otherwise positive observation are not yet confirmed, and may be due to relative short time in the CLC test reactor. Further CLC reactor operation and analysis are required.

The main CLC unit at Chalmers has been modified to include a number of new measurement systems and improvements to enable understanding the clean-up of the flue gases during operation. The main modifications are

- New cooler for better control of flue gas temperature
- New reactor for injection of oxidizing agent for controlled NO clean-up

- Installation of scrubber system for absorption of NO_2 and SO_2, including solvent recirculation and sub-system control

Experimental results have confirmed that

- SO_2 absorption is very efficient
- NO_2 is more difficult to absorb. Maximum removal of 85% was observed, but this required additional injection of Na_2SO_3. This experimental set-up is however a significant improvement on the more common Selective Non-Catalytic Reduction (SNCR), which is typically only 40% efficient.

A new configuration is planned for March 2019 to further improve the NO_2 removal efficiency and reduce use of chemical additives.

WP5 Ash and corrosion

A report summarizing the results of the corrosion testing is under preparation. During this reporting period one complementary corrosion test has been carried out to complete the picture of corrosion risks in the oxy-polishing unit. Cooperation with Chalmers University of Technology on bed materials has also taken place. This has resulted in a master's thesis at Chalmers, supervised by Dr. Maria Zevenhoven from Åbo Akademi University. The experimental work associated with a master's thesis on manganese based bed materials has also been undertaken during the autumn.

New sub-system for cooling and flue-gas clean-up at the Chalmers CLC test unit.

WP6 Upscaling and implementation and WP7 Bio-CCS in a low-carbon Nordic energy system

The 9th Finnish Flame Day

The Finnish Flame Research Committee (FFRC) organized the IX Flame Day on 23rd of October in Dipoli, Espoo. Flame Day is a bi-annual special forum for both industry and academia in the field of combustion technology. Representatives from the Finnish boiler manufacturers, Sumitomo SHI FW (Vesna Barisic, Chair of FFRC and Flame Day) and Valmet (Sonja Enestam, Co-chair of FFRC and Flame Day), hosted the event. About 60 persons participated, about half from relevant industry (energy utilities, boiler and equipment manufacturers) and about half from research institutes and universities.

Keynote talk from Toni Pikkarainen (VTT) spells out the increasing importance of achieving negative CO_2 emissions by bioenergy with CCS (BECCS). BECCS is fast becoming an essential technology to limit global temperature rise to <2°C.

Negative CO2-project had three presentations in the Flame Day. A keynote "Negative CO2 emissions by bioenergy with carbon capture and storage - why and how?" was given by Toni Pikkarainen, VTT. In the keynote it was emphasized the urgent need for NETs (negative emission technologies) to reach 1.5°C target and the possible consequences if we fail. The concept of bio-CLC, its potential for superior techno-economic performance and selected main results so far of the Negative CO2-project were introduced. In the technical presentations economic assessment of bio-CLC (Achieving lower cost negative CO2 emissions with a new bio-CLC technology) and results about bio-CLC ash behaviour (Chemical Looping Combustion of biomass – fate of ash forming elements) were presented by Tomi Lindroos (VTT) and Anders Brink, Åbo Akademi, respectively.

Program and presentations can be found from http://www.ffrc.fi/Liekkipaiva_2018.html, an article about the Finnish Flame Day (written by Philip Sharman, IFRF Director) from https://ifrf.net/ifrf-blog/the-9th-finnish-flame-day-ix-liekkipaiva/ and Twitter-moments in https://twitter.com/i/moments/1055008304416600064.

WP8 Dissemination

Our project members have attended several CCS and industry events both locally and internationally. In addition, they have been very active in dissemination, profiling and public outreach through their publications, attendance at other public events, newspaper articles, web articles, other outreach activities and more. The following lists give a complete summary of these activities since June 2018.

Publications, presentations and submissions

Lyngfelt, Anders; Daniel J.A. Johansson and Erik Lindeberg, Negative CO2 Emissions - An Analysis of the Retention Times Required with Respect to Possible Carbon Leakage, *submitted for publication (*and presented at *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia)

Lyngfelt, Anders; Magnus Rydén; Carl Linderholm and Tobias Mattisson, Chemical-Looping Combustion (CLC) of Solid Fuels (SF-CLC) - A Discussion of Operational Experiences, Costs, Upscaling

Strategies and Negative Emissions (Bio-CLC), *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia.

Linderholm, Carl; Anders Lyngfelt; Christian Azar; Sally Benson; Göran Berndes; Thore Berntsson; Josep G. Canadell; Philippe Ciais; Annette Cowie; Sabine Fuss; James E. Hansen; Filip Johnsson; Jasmin Kemper; Klaus Lackner; Fabian Levihn; José Roberto Moreira; Kristin Onarheim; Glen Peters; Tobias Pröll; Phil Renforth; Joeri Rogelj;; Pete Smith; Thomas Sterner; Detlef van Vuuren and Jennifer Wilcox, 1st International Conference on Negative CO_2 Emissions - Summary and Highlights, *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia.

Gogolev, I., Linderholm, C., Gall, D., Schmitz, M., Mattisson, T., Pettersson, J.B.C., Lyngfelt, A.,Chemical-Looping Combustion in a 100 kW Unit Using a Mixture of Synthetic Calcium Manganite and Natural Ilmenite as Oxygen Carrier, *5th International Conference on Chemical Looping,* Park City, Utah, 24-27 September 2018

Lyngfelt, A., Mattisson, T., Rydén, M., and Linderholm, C., 10,000 h of Chemical-Looping Combustion Operation – Where Are We and Where Do We Want to Go?, *Submitted for publication (Plenary at 5th International Conference on Chemical Looping,* Park City, Utah, 24-27 September 2018)

Onarheim, Kristin, Harlin, Ali, Arasto, Antti and Lehtonen, Juha. A strategy for turnig the Froest Industry Carbon Negative. *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia.

Mattison, Tobias, Normann, Fredrik and Lyngfelt, Anders. Fate of Nitrogen in Chemical-Looping Combustion: A review of Thermodynamics, Kinetics and Measurements. *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia.

Osman, Mogahid, Zaabout, Abdelighafour, Cloete, Schalk and Amini, Shahriar. Pressureized Chemical Looping Process for Power/Chemical Production with Inherent CO_2 Capture: A Review. *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia.

Thomasson, Tomi, Kärki, Janne and Pikkarainen, Toni. Techno-Economic Analysis of bio-CLC: Assessing the Nordic Policy Framework. *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia.

Langørgen, Øyvind, Saanum, Inge, Haugen, Nils Erland. SINTEF Energy Research. Chemical Looping Combustion of biomass in a 150 kWth CLC pilot unit., Poster presentation at the 5th *International Conference on Chemical Looping, September 24-27, Utah*. (*Note that this was originally accepted as*

oral presentation but we changed ourselves since we did not have time to analyse the new data from the test campaign in September just before the conference. A paper is being written instead.)

Cloete, Schalk, Tobiesen, Andrew, Morud, John, Romano, Matteo, Chiesa, Paolo, Giuffrida, Antonio, Larring, Yngve. Economic assessment of chemical looping oxygen production and chemical looping combustion in integrated gasification combined cycles, *International Journal of Greenhouse Gas Control*, Volume 78, 2018, Pages 354-363, ISSN 1750-5836, https://doi.org/10.1016/j.ijggc.2018.09.008.

Kärki, Janne (presenter), Sampo Mäkikouri, Cyril Bajamundi and Markus Hurskainen. "New business opportunities based on biogenic carbon dioxide utilization". As one business opportunity, the work included a techno-economic study of CHP plant with possibility for both carbon utilization and storage (bio-CLC). As the integrated concept brings benefits such as heat integrations and an oxygen supply, the economic feasibility of bio-CLC was found to increase under certain market conditions. *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia.

Peltola, Juho, Toni Pikkarainen (presenter) and Timo Niemi. ‘‘BIO-CLC Pilot Scale Experiments Combined with CFD Simulations: How to Improve the Performance by Better Design?’’ Proceedings of 5th International Conference on Chemical Looping, 24-27 September 2018, Park City, Utah, USA. Oral presentation.

Lindroos, Tomi, Magnus Rydén, Oyvind Langorgen, Esa Pursiheimo and Toni Pikkarainen. ‘‘Robust Decision Making Analysis of BECCS (bio-CLC) in a District Heating and Cooling Grid’’ was submitted to Sustainable Energy Technologies and Assessments on 5th December. Article is co-written by VTT, Chalmers and SINTEF.

Lindroos, Tomi. Achieving lower cost negative CO_2 emissions with a new bio-CLC technology. IX Flame Day. 23 October 2018, Espoo, Finland.

Pikkarainen, Toni. Negative CO_2 emissions by bioenergy with carbon capture and storage - why and how? IX Flame Day. 23 October 2018, Espoo, Finland.

Brink, Anders. Chemical Looping Combustion of biomass - fate of ash forming elements. IX Flame Day. 23 October 2018, Espoo, Finland.

Oral presentation at Clearwater Clean Energy conference , Florida June 2018 on the ongoing experiment.

Johansson, Jakob, et al. Pressurized control of NO_x and SO_x -focusing on the experiments performed at Chalmers. Oral presentation at *14th International Conference on Greenhouse Gas Control Technologies*, GHGT-14, 21st -25th October 2018, Melbourne, Australia.

Johansson, Jakob, Heijnesson, Anette Hultén, Ajdari, Sima, Nilsson, Pär, Samuelsson, Marie, Normann, Fredrik and Andersson, Klas.: Gas-Phase Chemistry of the NO–SO_2–ClO_2 System Applied to Flue Gas Cleaning. Peer reviewed article in *Industrial & Engineering Chemistry Research,* 2018 57 (43), 14347-14354
DOI: 10.1021/acs.iecr.8b03067

Other Outreach activities

Newspaper, interviews, radio, web, magazine articles

Lyngfelt, Anders, Infångning och lagring av koldioxid är en beprövad teknik, Dagens Nyheter, Replik DN Debatt, 15 oktober 2018, https://www.dn.se/debatt/repliker/infangning-och-lagring-av-koldioxid-ar-en-beprovad-teknik/
Capture and storage of carbon dioxide is a proven technique, Dagens Nyheter, Commentary

Lyngfelt, A.; Nina Ekelund, Fabian Levihn, Mathias Fridahl and Markus Larsson, Så kan insamling och lagring av koldioxid finansieras, Aktuell Hållbarhet, 2018-09-07, https://www.aktuellhallbarhet.se/sa-kan-insamling-och-lagring-av-koldioxid-finansieras/
How to finance carbon capture and storage, Journal of Current Sustainability

Dagens Nyheter (helt uppslag, 30 nov/1 dec), se också bilagor:
https://www.dn.se/nyheter/vetenskap/att-lagra-koldioxid-ar-nodvandigt-men-inte-tillrackligt/
To store carbon dioxide is necessary but not enough. Interview by Sweden's leading business newspaper, Dagens Nyheter, of Dr. Anders Lyngfelt.

Links to all lecture and a poster by Anders Lyngfelt et al. in selected events can be found on the following links:

http://www.entek.chalmers.se/lyngfelt/presentations/presentations.html
Chemical-Looping Combustion of Solid Fuels - A Discussion of Operational Experiences, Costs, Upscaling Strategies and Negative Emissions
(presentation) GHGT14, October 21-25, 2018, Melbourne

Negative CO2 Emissions - An Analysis of the Retention Times Required with Respect to Possible Carbon Leakage
(presentation) GHGT14, October 21-25, 2018, Melbourne

1st International Conference on Negative CO2 Emissions - Summary and Highlights
(poster) GHGT14, October 21-25, 2018, Melbourne

Flach, Todd. 'Carbon Capture and Storage: Global and Norwegian Status'. Presentation for the Finnfjord workshop on CCUS, Hamn i Senja, September 27th, 2018.

Flach, Todd. 'Input in Open Hearing on Oslo County's 2040 Development Plan: Opportunities for Oslo in Bio-CCS'. Oral report at the hearing at the Oslo City Hall, November 16th, 2018.

Flach, Todd. 'Oslo: The World's Leading Carbon-negative City (presentation)'. Breakfast seminar hosted by the Oslo Climate Bureau, October 16th, 2018

Även länk till TV2 direktsändning för ESO (den första nedan): https://www.svtplay.se/video/18163439/forum/forum-27-nov-09-00-2?start=auto (Dr. Lyngfelt pratar efter ganska precis 4 timmar)
Direct sending of seminar hosted by the Swedish Expert Group on Studies in Public Economy (ESO), on television channel SVT2 (Nov. 27th, 2018). Dr. Anders Lyngfelt speaks on negative emissions 4 hours into the television sending of the seminar.
Minusutsläpp genom Bio-CCS/BECCS
Expertgruppen för Studier i Offentlig Ekonomi (ESO), Stockholm, 27 november, 2018
Negative emissions by applying Bio-CCS/BECCS. Expert group for The Studies of the Public Economy.

Minusutsläpp - Varför? När? Var? Hur?
Svenskt seminarium om radikal minskning av klimatgasutsläpp i processindustrin, Energimyndigheten, Stockholm, 21 november, 2018
Negative emissions – Why, When, Where and How? Swedish seminar on radical reductions of greenhouse gases in the process industry.

Minusutsläpp - Så kan vi tvätta atmosfären på koldioxid
Naturskyddsföreningen i Göteborg, 16 oktober, 2018
Negative emissions – How to rinse carbon dioxide out of the atmosphere. Environmental Protection Association in Gothenburg.

BECCS i Norden - De nordiska länderna har utomordentligt goda förutsättninar för Bio-CCS Möte Industrial Advisory Board, Chalmers Styrkeområde Energi, 19 juni 2018
BECCS in the Nordic Countries-The extraordinary, positive conditions in this region for Bio-CCS. Meeting in the Industrial Advisory Board.

Sammanfattning, slutsatser och lärdomar av "International Conference on Negative CO_2 Emissions"
Möte Industrial Advisory Board, Chalmers Styrkeområde Energi, 19 juni 2018
Summary, Conclusions and Lessons Learned from the "International Conference on Negative CO_2 Emissions" Meeting in the Industrial Advisory Board, Chalmers University.

‘‘Chemical looping using biomass – corrosion risks in the heat recovery section of the fuel reactor’’ presented at the joint meeting of the Polish and the Scandinavia-Nordic sections of the Combustion Institute, in Krakow, Poland. September 6-7, 2018.

Åbo Akademi University arranged an industry information exchange meeting. Results from the Negative CO_2 project were presented to industrial stakeholders, including boiler manufacturers and end users. September 19-20, 2018.

Tomi Lindroos (VTT). Negatiivisilla päästöillä hiilineutraaliksi (in English: Carbon neutrality by negative emissions). Article in BioEnergia (in English: BioEnergy) magazine, 5/2018.

M.Sc. thesis

‘‘Ash interactions with oxygen carriers Glödskal and LD-slag in biomass-CLC’’, Felicia Eliasson, Chalmers University of Technology

Upcoming events

COP24 **Where: Katowice, Poland When**: **December 3-14, 2018**

Contacts

For general questions about the project, please contact the Chalmers University of Technology:

Anders Lyngfelt anders.lyngfelt@chalmers.se +46 (0) 31 772 1427
Magnus Rydén magnus.ryden@chalmers.se +46 (0) 31 772 1457

www.nordicenergy.org/flagship/negative-co2/