Negative CO_2

Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

Negative CO_2 Newsletter #3 October 2017

This is the third 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 September 2016 to September 2017.

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

In this issue:

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).

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.

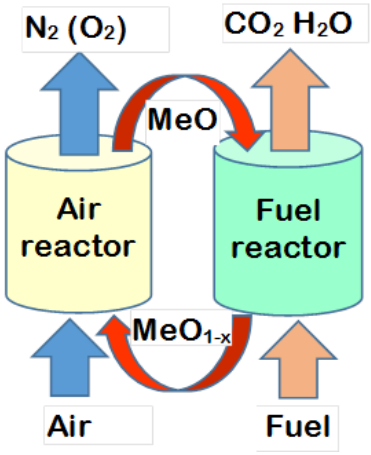


Fig. 1. Chemical-Looping Combustion

Negative CO_2

Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

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
- Foster Wheeler Energia
- Göteborgs Energi
- Titania A/S
- Arbaflame A/S
- Fores

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.

Chemical Looping Combustion

Chemical Looping Combustion (CLC) is a technology able to capture CO_2 from energy production at relatively low cost and with a large efficiency. While conventional combustors burn fuel with ambient air, containing the needed oxygen as well as a lot of nitrogen, CLC installations burn fuel with solid metal oxide particles.

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).

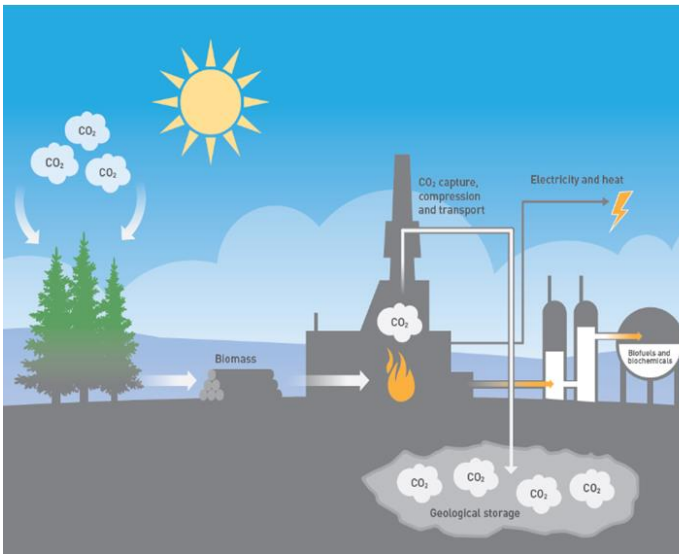


Fig. 2. Electricity and biofuels production with Bio-CCS (Illustration by doghouse.no/sintef)

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

Higher CO_2 prices increase operating hours

VTT (Working package 6) has conducted a preliminary techno-economic analysis for a 100 MWth Combined Heat and Power (CHP) plant with different technologies (air-fired, CLC and oxy-fuel) in a municipal Nordic/Finnish energy system. Varied market situations were set up to evaluate the operation of the plant utilizing different shares of Nordic biomass fuels.

In the simulated baseline case, the break-even price of CLC compared to the air fired plant was found to be around 35 €/t CO_2. Load-duration curves (fig. 2) emphasize the importance of the negative CO_2 emissions: the full load operating hours of CLC are drastically increased with higher prices of emitted CO_2. Compared to previous studies, the break-even prices were found to have weak sensitivity to the varied parameters (e.g. price of biomass, price of electricity and biomass percentage in fuel mixture). This is mainly explained due to possibility to schedule the operation differently based on the market conditions, leading to different shares of generated electricity and district heat in each case.

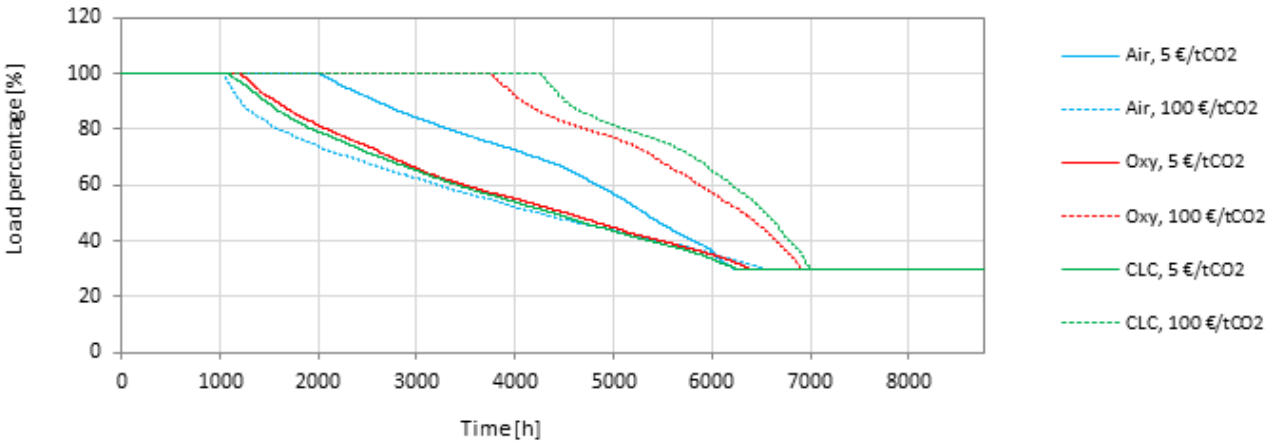


Fig. 3 Load-duration curves in the baseline feasibility comparison of the air-fired, oxy-fuel and CLC plants: biomass price of 20 €/MWhfuel with two varied prices of emitted CO_2 (5 €/tCO_2 and 100 €/tCO_2).

With constrained optimization, the importance of realistic boundary conditions in the model is highlighted. Technical questions have to be answered: what actually is the minimum ramp rate of the CLC plant, or how fast can it start up? Therefore, the study will continue by improving the model using inputs from the other work packages. The next simulation cases will focus on the different Nordic countries, allowing policy frameworks to be analyzed. In addition, interesting simulation cases such as flexible carbon capture will be carried out.

Wood char gives high performance

At the European Biomass Conference and Exhibition (EUBCE), the presentation "Chemical Looping Combustion of Solid Biomass – Performance of Ilmenite and Braunite as Oxygen Carrier Materials" was given by Toni Pikkarainen, VTT, in a session called "Bioenergy in integrated energy systems". In the presentation and paper (published in conference proceedings) the urgent need for negative CO_2 solutions was highlighted to reach the ambitious climate targets – global temperature rise below 2°C – set in Paris agreement in 2015. The pilot scale experimental results were presented covering 19 test runs with two types of oxygen carriers and three types of wood based fuels.

Very good performance was obtained with wood char (with low volatile content) while conversion of volatiles of wood pellets needs some improvements by enhancing the mixing in the fuel reactor.

Fig. 4. Chemical looping combustion pilot scale test facility of VTT, located in Espoo, Finland. *(Credit: VTT)*

The results also indicated that Bio-CLC can reduce the risk of high temperature corrosion enabling the option to use higher steam values compared to conventional biomass combustion, improving the power generation efficiency.

Working package progress

During this period in the project, much progress has been made with regards to scientific and technical results, and in terms of dissemination activities. The eight working packages in the project have gathered additional relevant data, and the outcomes have been presented on a wide variety of platforms. Some of the working packages and there results are presented below. Of particular interest were results connected to acquired data on materials, oxygen carrying particles and techno-economic upscaling.

Work package 2 – SINTEF lab prepared for biomass combustion

The 150 kW CLC pilot plant at SINTEF Energy Research in Trondheim had its first successful operation in CLC mode in June 2016, operating on methane gas as fuel. Since then the CLC pilot has been used within the EU FP7 project "SUCCESS" until February 2017. Up to then, the reactor system had fuel introduction system only for gaseous fuels. During spring and summer 2017 the pilot plant has been modified and prepared for operation on biomass within the Work Package 2 of the Negative CO_2 project.

Work package 3 – Oxygen carrier materials

Several families of the naturally occurring minerals are studied up to this point of the project. These selection experiments are performed with model gas in thermogravimetric analysers.

2016 was the second period of successful operation of biomass in 100 kW pilot with a manganese ore supplied by the global material solutions company Sibelco. The results are currently being evaluated. Additionally, for the first time, biomass was successfully used in a 100 kW pilot plant with a sintered manganese ore from China. The results were presented by Carl Linderholm (see list of publications) at the European Biofuels Conference and Exhibition (EUBCE) in [month] 2017.

Now the direction of the works is towards more realistic conditions using biomass as the solid fuel. SINTEF has developed a micro reactor for fluidized bed testing of the selected oxygen

carrier materials together with the biomass selected in the project. The selected materials will be tested in the period of October and November 2017.

Work package 4 – Flue gas treatment

A future Bio-CLC plant will need an efficient flue gas treatment system to convert raw flue gas flowing out from the fuel reactor to clean CO_2, suitable for transport and storage. The earlier Nordic Energy Research project "NORDICCS", recommended CO_2 transport by ship alternative as a fitting option for the Nordic countries (Røkke, N.A. et. al. (2016)). This has been further concretised through the Norwegian Government's plan of realising at least one full-scale CCS demonstration facility in Norway.

Such a Bio-CLC plant will generate about 1470 tonnes of CO_2 per day, equal to about 1400 m^3/day using a medium pressure liquid state CO_2 condition (about 15 bar and minus 25 °C). Ships for transporting CO_2 at this condition will be in the range of 7400 – 7700 m^3 capacity.

Work package 5 – Ash and corrosion issues: Interaction of ash with Oxygen carriers

Within WP5, Ash and Corrosion Issues, the influence of alkali, especially potassium on the oxygen carrier capacity of ilmenite and on corrosion caused by the contaminated bed material has been investigated.

The influence of potassium enriched ilmenite deposits on the corrosion of boiler materials in air and fuel reactors in chemical looping combustion have been studied in well-controlled laboratory tests. In total, seven different steels from low-alloy to high-alloy have been studied.

The results suggest that under the conditions studied, potassium enrichment of ilmenite does not enhance the corrosion of typical materials for the fuel reactor while the risk for corrosion is somewhat higher in the air reactor. Some complementary corrosion tests are still ongoing. Especially the influence of alkali chloride deposits in the air reactor is studied.

Other project news

Health and safety commitment: test show dust concentration well below limit values

Focus on health, safety and environment (HSE) is important in laboratory work and in operation of pilot plants. A specific issue with CLC is the use of fine particles being fluidized and looped between the reactors to transport oxygen from the air reactor to the fuel reactor. During test operation, there may be need for some manual handling of the particles, such as when emptying the reactor system, refilling the system, and when doing make-up filling during operation.

In January 2017, SINTEF Energy Research hired the company "Stamina Helse" to do dust measurements at the CLC pilot plant during one day of operation. Quality dust masks are being used when doing such handling but it was of interest to have some idea of the dust concentrations in the tent hall where the reactor is mounted. Three pump and filter units were used, of which two were stationary and the third was mobile and placed on one operator, close to the face area.

Subsequent analysis of the filters provided the amount of both the total dust and respiratory dust. All the samples showed values well below limit values except the one carried by the operator where the amount of total dust was higher than the limit value. This was attributed to manual handling at some occasions during the day.

Biomass feeding system

A feeding system for wood pellets had to be constructed and mounted. To avoid leakage and backflow problems it was decided to have a pressurized system with continuous flushing of nitrogen.

The wood pellet storage tank, the feeding screw and the connecting pipes will essentially have the same pressure as the reactor at the location where the wood pellet is introduced, in the bottom of the fuel reactor. Valves are mounted on each side of the storage tank, so that it is possible to refill pellets during operation without having back-flow through the system.

Fig. 5. Mid-section of the 150 kW CLC reactor system at SINTEF Energy Research.

The reactor already had a screw conveyor for oxygen carrier particle extraction, which were very seldom used. It was decided to modify this screw and use it as the feeding screw, as the capacity fitted well and it was constructed to be gas tight. The control system for screw motor was also already installed in the system.

Outreach activities

GHGT-13 Lausanne

During the 13th Greenhouse Gas Control Technologies Conference (GHGT-13) in Lausanne (Switzerland) on November 16th 2016, Bellona Europa and the IEA Bioenergy Task 41 organised their second Bio-CCS workshop. The topic of the event was sustainability and the impact of Bio-CCS and Bio-CLC on the emission of greenhouse gasses (GHG).

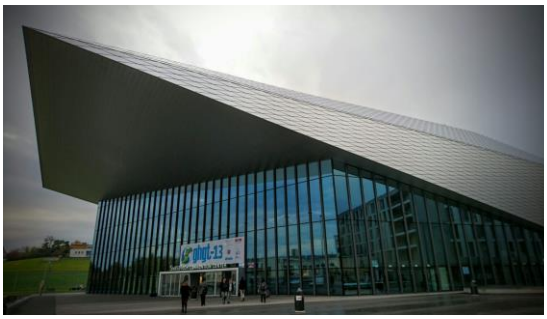


Fig. 6. GHGT-13 Lausanne
(Credit: Bellona Europa)

See also: http://bellona.org/news/ccs/2016-11-bellona-co-hosts-bio-ccs-workshop-in-lausanne

Annual Public Workshop 2017 at Swedish Parliament

Fig 7 From left to right: Anders Lyngfelt (Chalmers, NER Negative CO_2), Jonas Helseth (Bellona Europa), Stefan Sandelin (Cementa), Trude Sundset (Gassnova). *(Credit: Bellona)*

On 15 June, Bellona, Nordic Energy Research and the Moderate Party of Sweden organized the Annual Public Workshop of the Negative CO_2 flagship project at the parliament of Sweden.

Central to this yearly seminar was the commitment of the Swedish government to achieve national carbon neutrality by 2045 and carbon negativity after that. Bio-CLC is one of the most suitable pathways in which the Swedish goals can be achieved. See also:

http://bellona.org/news/ccs/2017-06-annual-public-workshop-2017-starting-the-swedish-norwegian-dialogue-on-bio-ccs

Negative CO_2 at EUBCE 2017

The European Biomass Conference and Exhibition (EUBCE) is established as one of the most important events for the biomass community worldwide in size, international acceptance and relevance.

Fig. 8. Toni Pikkarainen (VTT)

At the European Biomass Conference and Exhibition (EUBCE) 2017, Negative CO_2-project was well involved in European Biomass Conference and Exhibition (EUBCE) in Stockholm, Sweden, 12th-15th of June. In total, two presentations with full papers and four posters were accepted to EUBCE disseminating the results of the project.

Energy Laboratories for the Future

On June 12th 2017, the joint Thermal Energy lab at NTNU (Norwegian University of Science and Technology) and SINTEF in Trondheim was re-opened after one year of major rebuild and modernisation. The re-opening of the lab was celebrated together with the inauguration of ECCSEL ERIC, a program that will manage and develop the pan-European CO_2 capture and storage lab infrastructure, as well as the 100-year jubilee of the Waterpower Laboratory at NTNU. The arrangement and conference involved high level representatives from both EU and the Norwegian Government.

As part of the arrangement there were poster stands and guided group tours through the lab. One stand was devoted to the CLC activity at SINTEF included the ongoing work in the Negative CO_2 project, developing a carbon negative solution through the Bio-CLC process.

7th High Temperature Solid Looping Cycles Network Meeting

At HTSLCNM7 in Luleå, September 4-5, Anders Lyngfelt talked about Bio-CLC under the heading ‘‘*Bio-CLC: Need for, 100-kW operational results and potential in the Nordic Region*’’.

Upcoming events

Bellona CO_2 infrastructure breakfast seminar

Where: Kulturhuset, Youngs gate 6, Oslo
When: 07:45-09:30, 7 December 2017

With a full-scale Norwegian CO_2 network underway, the Nordic countries are in an excellent position to become the world's first regional CO_2 network.

Sweden and Finland have large point emissions of CO_2 from biomass. Norway has plenty of offshore sites where it can store enormous amounts of CO_2. The Nordics are therefore in a natural position to work together to establish a CO_2 capture and storage network.

Seven out of eight parties in the Swedish parliament have stated that Sweden needs to become carbon neutral by 2045, and carbon negative after that. This was officially declared in Sweden's new climate policy framework.

How can the Nordic countries collaborate in order to establish a full-scale regional CCS infrastructure?

Confirmed speakers include Johan Hultberg (MP Moderate Party of Sweden, co-author of the Swedish climate framework), Elisabeth Undén (Green Party Gothenburg), Trude Sundset (CEO, Gassnova), and Jonas Helseth (Director of Bellona Europa).

Contact Johan Verbeek Wolthuys (Bellona) here to sign up.

Negative CO_2

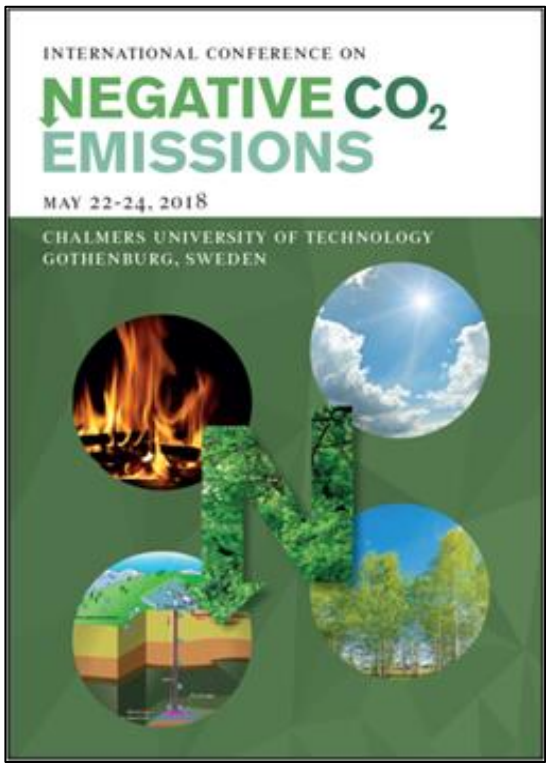
Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

International Conference on Negative CO_2 Emissions

Where: Chalmers University of Technology in Gothenburg
When: May 22 to 24 2018

The first International Conference on Negative CO_2 Emissions is being organized at Chalmers.

The purpose of the conference is to bring together a wide range of scientists, experts and stakeholders, in order to engage in various aspects of research relating to negative CO_2 emissions. This will include various negative emission technologies, climate modelling, climate policies and incentives.



More info at:
www.negativeCO2emissions2018.com

Call for abstracts:

- Use the template provided on project website.
- Email to: NegativeCO2@chalmers.se
- Abstract (one page): *December 1, 2017*
- Notification of acceptance: *January 15, 2018*
- Deadline full paper: *April 1, 2018*

Background for the conference

The objective of the Paris Agreement is to limit global warming to well below 2ºC, and to pursue efforts to limit the temperature increase to 1.5ºC. The IPCC Fifth Assessment Report quantified the global "carbon budget", that is the amount of carbon dioxide that we can emit while still having a likely chance of limiting global temperature rise to 2 degrees Celsius above pre-industrial levels.

The exact size of the carbon budget cannot be specified with high confidence since it depends on many uncertain factors, including emission pathways for non-CO_2 climate forcers.

This said, the remaining budgets for the 1.5ºC and 2ºC targets have been estimated at about 200 and 800 Gt of CO_2. With unchanged present emissions at about 40 Gt CO_2/year these

budgets would be exhausted in as few as 5 and 20 years, respectively. Consequently, most of the IPCC emission scenarios able to meet the global two-degree target require overshooting the carbon budget at first and then remove the excess carbon with large negative emissions, typically on the order of 400-800 Gt CO_2 up to 2100.

At the same time as negative emissions appear to be indispensable to meet climate targets decided, the large future negative emissions assumed in climate models have been questioned and warnings have been raised about relying on very large and uncertain negative emissions in the future. With the future climate at stake, a deeper and fuller understanding of the various aspects of negative emissions is needed.

Dissemination

Publications

Linderholm, C., Lyngfelt, A., Rydén, M., and Schmitz, M. Chemical-looping combustion of biomass in a 100 kW pilot, presentation at *25th European Biomass Conference and Exhibition (EUBCE)*, June 12-15, Stockholm, Sweden, 2017

Lyngfelt, A., and Nieminen, M. Bio-CLC, a novel approach for attaining negative emissions of CO_2 at reduced cost, extended abstract and poster presented at *25th European Biomass Conference and Exhibition (EUBCE)*, June 12-15, Stockholm, Sweden, 2017

Lyngfelt, A., Negative emissions of CO_2 at reduced cost using Chemical-Looping of Biomass, *BE sustainable*, Issue 8, (May/June 2017) 24-26

Lyngfelt, A., Thore Berntsson, Mathias Fridahl, Filip Johnsson, Markus Larsson, Jan Pettersson och Elisabeth Undén. En svensk strategi för negativa utsläpp, Fores, Policy Brief 2017:1 http://fores.se/wp-content/uploads/2017/06/Fores_Policy_Brief_Negativa_Utslapp_FINAL.pdf

Rydén, M., Anders Lyngfelt, Øyvind Langørgen, Yngve Larring, Anders Brink, Sebastian Teir, Hallstein Havåg, and Per Karmhagen. Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass – a Nordic Energy Research Flagship Project, *Energy Procedia* v 114, p 6074-6082, 2017

Conference publications

Pishahang, M., Martin F. Sunding, Yngve Larring; Utilisation of Naturally Occurring Materials and Slags in the Bio-Based Chemical Looping Combustion, abstract and poster presented at *25th European Biomass Conference and Exhibition (EUBCE)*, June 12-15, Stockholm, Sweden, 2017

Zevenhoven, M., Christoffer Sevonius, Patrik Salminen, Daniel Lindberg, Anders Brink, Patrik Yrjas, Leena Hupa, "Defluidization of ilmenite, an oxygen carrier for chemical looping combustion", 30th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems. July 2. - 6. 2017, San Diego, California.

M.Sc. thesis

Fredrik Hildor, "Interaction between potassium salts and ilmenite under reducing conditions relevant for Chemical Looping Combustion (CLC)", M.Sc. thesis, Chalmers 2017.

Media

- Øyvind Langørgen of SINTEF Energy Research was interviewed about CLC by Gemini.no, a webzine presenting research news from the Norwegian University of Science and Technology and SINTEF to the general public. (Incl. short video). 30 January 2017. http://gemini.no/2017/01/fanger-co2-metode/
- The article above was also published on TU.no, the webpage of Teknisk Ukeblad, the largest Norwegian technological news magazine. (Incl. short video). 30 January 2017. https://www.tu.no/artikler/forskning-i-energilaboratoriet-pa-tiller-fanger-de-co2-med-en-ny-metode/375645
- Øyvind Langørgen of SINTEF Energy Research and Glen Peters of Cicero Center for International Climate Research are interviewed by NRK.no/Viten about the need for CCS and CLC as a possible CO_2 capture technology. (NRK.no is the news website of the national Norwegian broadcaster and NRK.no/Viten is their research news section). 11 February 2017. https://www.nrk.no/viten/vil-gjore-det-billigere-a-fange-co_-1.13369203

Negative CO_2

Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

Video

The CLC pilot plant at SINTEF Energy Research is situated at a SINTEF facility a few kilometres outside of Trondheim and the campus. We were therefore asked to make a small movie from the pilot plant that could give an impression of the plant and its operation. The movie has been put on YouTube and can be found at this link: https://www.youtube.com/watch?v=T0FrFCv1SK0&feature=youtu.be

Contacts

For general questions about the project or subscription, 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/