Negative CO_2

Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

Negative CO_2 Newsletter #4 June 2018

This is the fourth 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 October 2017 to June 2018.

The objective of this project is to demonstrate an effective pathway of both producing 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:

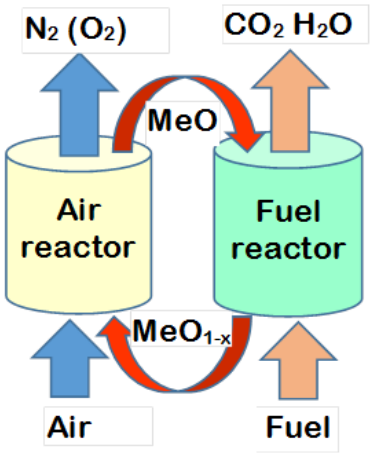
- Chalmers University of Technology
- The Bellona Foundation
- Sibelco Nordic AB
- SINTEF Energy Research
- SINTEF Materials and Chemistry
- VTT Technical Research Centre of Finland Ltd
- Åbo Akademi University

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
- Foster Wheeler Energia
- 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.

Negative CO_2

Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

Chemical Looping Combustion

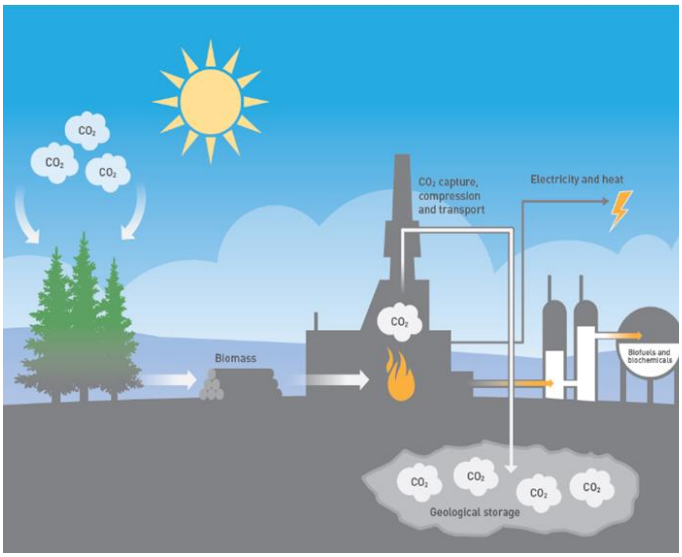
Chemical Looping Combustion (CLC) is a technology able to capture CO2 from energy production at relatively low cost and with high efficiency. Conventional combustors burn fuel with ambient air, which contains the needed oxygen as well as a lot of nitrogen, and this makes separating the CO2 after combustion 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 CO2 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 CO2 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 CO2 capture dramatically.

Biomass and CLC

The usage of sustainable biomass as the fuel in this process allows for the efficient withdrawal of CO2 from the atmosphere. Biomass binds carbon as it grows, thus taking CO2 (carbon dioxide) from the atmosphere. When the biomass is used in energy production, the CO2 is recreated and returned to the atmosphere. But, if the CO2 is instead captured and subsequently stored underground, that CO2 will never end up back in the atmosphere again. This means that CO2 removed from the atmosphere by the biomass as it grew, is permanently removed from the atmosphere. The result is negative CO2 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

In the time between September 2017 and June 2018, the work packages have made significant progress. In addition, there has been very high activity regarding publication, profiling and dissemination.

Chalmers University, led by the flagship coordinators Anders Lyngfelt and Magnus Rydén, hosted the International Conference on Negative CO_2 Emissions in Gothenburg, May 22-24. The program included 11 keynote speakers, 145 oral presentations held in 5 parallel sessions, 12 plenaries, with 3 panel discussions and 30 posters. There were 275 participants.

During the same week as this conference, this flagship project made major contributions to the side event on May 24th as part of the Nordic Clean Energy Week in Copenhagen and Malmö.

On June 5th, Bellona hosted The Annual Public Workshop in Oslo that brought together various national experts and international commercial players from Finland, Sweden and Norway, who shared their visions of negative emissions potential in the Nordic countries and beyond.

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

In October and November 2017, the first biomass test campaigns were performed in the 150 kW CLC pilot unit at SINTEF ER. This was also the very first operation with solid fuels in this pilot unit. A stable biomass feed-rate equivalent to 140 kW_{th} was obtained, which is rather large compared to other studies found in the literature. In fact, 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.

Test campaigns were also completed using the pilot plants at Chalmers and at VTT.

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

WP2 Pilot Plant Operation

First operation with biomass fuel in the 150 kW CLC pilot unit at SINTEF Energy Research achieved autumn 2017

During the solid biomass pilot testing on the 150 kWt plant (SINTEF) in October-November 2017, the biomass feed was whole "black-wood" pellets, i.e. steam exploded wood pellets provided by the commercial supplier Arbaflame AS.

They were mainly fed without any treatment, i.e. as whole pellets. The oxygen carrier was ilmenite from Titania AS. The operation of the reactor was nearly auto-thermal, as the only additional heating of the reactor was preheating of the primary air for the air reactor. The minimum oxygen demand was calculated to about 23% and the CO2 capture efficiency varied between 94 – 97%. For a period of constant fuel feed of 140 kW it was found that the CO2 yield was 80 – 84%.

150 kWt CLC unit at SINTEF

'Black wood pellets' used in the test campaign November 2017. Delivered by Arbaflame AS.

These results are in line with results found in literature. The operation was without any steam addition to the fuel reactor. Steam would increase the gasification reaction rate and improve fuel conversion and capture efficiency. A steam generator is now being installed so that the next test campaigns will have steam available.

Control room at the 150 kWt plant at SINTEF. Inge Saanum at the controls.

The 150 kW CLC unit at SINTEF ER was originally designed for gaseous fuels. During 2017, the system has been prepared for biomass fuel. An improved fuel feeding system for fine fuel particles together with some other improvements will be installed and used in the next test campaign planned for Q4/2018.

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

The 2nd test campaign using VTT's 50 kW CLC unit

was carried out with braunite, which is a manganese ore from flagship partner Sibelco, as oxygen carrier. Both reference fuels were tested, i.e. white and black wood pellets. In addition, wood char with lower volatile content was tested. The results were compared with the results of the 1st test campaign with ilmenite (iron-titania ore from Titania AS). Performance of braunite was found to be better than ilmenite. Much better performance was obtained with wood char than with wood pellets. High volatile content of biofuels was found to be the limiting factor of performance, thus solutions for improved contact between volatiles and oxygen carrier should be strived for. The 2nd test campaign fulfils Milestone 2.5, and this was achieved 6 months before the project plan and schedule. An additional 3rd test campaign is planned for Q4/2018, enabled by lower costs than planned of the bio-CLC unit construction works in 2015-16. A new design of the bio-CLC fuel reactor will be tested in the 3rd test campaign.

The test campaign in Chalmers 100 kW CLC unit using its new post-oxidation chamber was performed on time according to plan in late 2017. The oxygen carrier was manganese ore ("Sinaus") and both reference fuels was used, i.e. black and white wood pellets. Gas conversion during operation was up to 75%, and CO_2 capture was close to 100%. Both of these parameter results are considered to be technical successes.

Negative CO2 annual project meeting in Trondheim April 17th - 18th

The meeting was hosted by SINTEF Energy Research. As part of the meeting there was also an excursion to the 150 kW CLC pilot unit at the Tiller research park.

WP3 Oxygen carrier materials

Site visit by flagship partners at SINTEF in April 2018 to their 150 kWt CLC research reactor.

This work package was mainly carried out in previous project period 2016-2017 because this work package paves the way for selection and use of oxygen carrier in the pilot units in WP2. During 2017 mostly post-test characterisation of samples tested in the large units were carried out. Ilmenite that had been run in the SINTEF ER pilot was examined and the results indicate the absence of reaction with certain common ash components, which is a positive result, but that the particles separated partially into iron and titanium rich phases with iron frequently diffusing to the surface of the particles forming an active layer. This indicates a shorter lifetime of this type of oxygen carrier, which reduces the utility of the particles. Higher activity in the work package is expected for 2018.

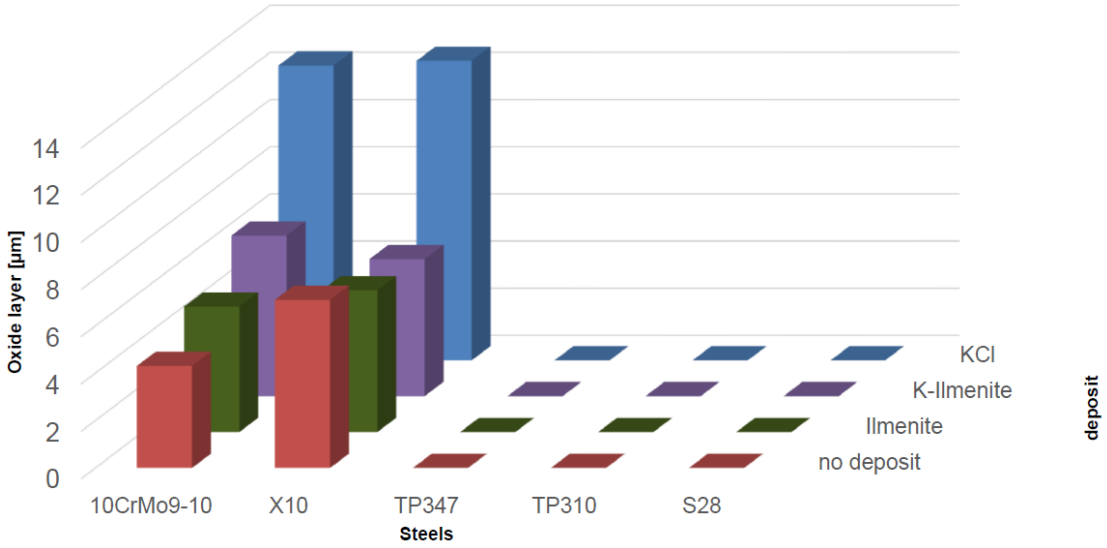
WP4 Flue gas treatment

Experimental work with the novel flue gas cleaning concept is slightly delayed, but the milestone in Q4/2018 should be achievable. The post-oxidation chamber of Chalmers 100 kWt unit has been used in several tests, including the campaign described above. However, additional work with pure oxygen will hopefully be made in 2018 in connection with planned operation in other projects.

WP5 Ash and corrosion

Biomass ash may cause bed sintering and corrosion of heat transfer surfaces. In the worst case, if not managed, this could severely limit operations of a Chemical Looping Combustion (CLC) unit. It is therefore the goal of this work package to investigate these risks. Stem-wood is usually a non-problematic fuel, but cheaper fractions such as bark, short rotation coppice and agricultural waste often cause corrosion or operational problems in biomass combustion. To investigate corrosion risks in CLC, laboratory tests have been carried out under conditions mimicking either the fuel- or the air reactor, which in operation can have very different and therefore different risk profiles regarding particularly corrosion. The analyses of the metal samples indicate that corrosion issues in biomass CLC are less severe than in standard biomass combustion. Especially the conditions in the air reactor

are such that significantly higher steam parameters seem possible from a corrosion point of view. In addition, the reducing conditions in the fuel reactor seem to destabilize KCl.



Measured oxide layer thickness of heat transfer surface samples exposed to a CO_2/H_2O atmosphere containing 500 pp HCl for one week. The material temperature was 450 °C. Only low alloy steel showed sign of minor corrosion.

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

Progress has been made in three categories: impact, Nordic-level relevance and dissemination. In order to highlight the novelty of the work, focus was put on the flexibility of bio-CLC: the option for flexible carbon capture was implemented in the model and is to be further expanded with flexibility parameters gained from the pilot plant operation. In addition, efforts were made to include reserve market simulation along with dynamic plant features to the model, as the significance of the load limits and ramp rates was highlighted in the simulation cases.

Regarding the Nordic-level relevance, work started on identifying the near-term expected policy framework in more detail for each of the Nordic countries. By using the information in the model, results and conclusions that are more general are achieved, offering a baseline for evaluating and proposing new policy mechanisms. Finally, work has been started to create an interactive web portal, allowing the key message in the results to be communicated more effectively. The web portal will combine the results of WP6 and WP7 as a whole, focusing on the area level (WP7) and case level (WP6) with different variable parameters.

Preliminary evaluation of potential demonstrations has also been discussed and evaluated at the project management level. The political and economic conditions for demonstration of bio-CCS based on CLC are currently unfavourable but any changes in political context might change the situation.

WP8 Dissemination

In this period the flagship partners organised, hosted and participated in two conferences in the Nordic countries. In addition, the flagship project held its the Annual Public Workshop.

International Conference on Negative CO2 Emissions May 22-24, 2018. Gothenburg, Sweden

Chalmers University, led by the flagship coordinators Anders Lyngfelt and Magnus Rydén, hosted the International Conference on Negative CO_2 Emissions in Gothenburg, May 22-24. This is the first international conference that focused on this theme. The program included 150 oral presentations held in 5 parallel sessions, 12 plenaries, with 3 panel discussions and a number of posters.

The conference gathered the world's leading scientists in the field of negative CO_2 emissions. This includes lead authors of the important IPCC 1.5-degree report to UN that will be released later this year. It includes the leading scientists in the fields of IAMs (Integrated Assessment Models), biogenic storage in soils, forests and with biochar, BECCS technology development, policy, direct air capture, weathering, as well as prominent persons like State Secretary Eva Svedling (for climate) and climate researcher James Hansen. **Members of this NER flagship project presented seven technical papers.**

Nordic Clean Energy Week Side Event, May 24, 2018. Copenhagen, Denmark

In the same week, this flagship project made major contributions to the side event on May 24th as part of the Nordic Clean Energy Week in Copenhagen and Malmö. This side event was hosted by Aalborg University in Copenhagen, and expanded on the theme 'Sustainable Energy Systems-Smarter, Integrated and CO_2-Negative'. All three NER flagship projects were represented with a number of presentations. **Our flagship project partners held 5 presentations that highlighted their latest project results. These presentations are listed below.**

Annual Public Workshop, June 5th, 2018. Oslo, Norway

Bellona organised and hosted a seminar in Oslo that brought together various national experts and international commercial players from Finland, Sweden and Norway, who shared their visions of negative emissions potential in the Nordic countries and beyond. Our own flagship coordinator, Anders Lyngfelt, gave his insights on the situation and the possibilities in developing negative emissions solutions, using the latest conference results and highlights from the International Conference on Negative CO2 Emissions in Gothenburg in May (summarised above).

In addition, the leader of Sweden's Fossil-Free Competitiveness Working Group, Svante Axelsson, gave his inside view on how CCS can contribute to the official GHG reductions goals in Sweden. The main audience was Norwegian politicians, who will be voting on the revised national budget for Norway in the following days, which includes line-item funding for the next phase of the three CO2 capture projects.

See web article on http://bellona.no/nyheter/co2-fangst-og-lagring/2018-06-nordens-gylne-co2-mulighet (Norwegian).

Among the participants were four members of the Norwegian parliament from four different political parties who are actively engaged in the most important political processes regarding development of CCS in Norway. The parliament members reflected on the current political processes in a panel discussion facilitated by Bellona's CCS coordinator, Olav Øye.

The following text lists publications, events, newspaper articles, web articles, other outreach activities in addition to these and more.

Publications, presentations and submissions

M. Zevenhoven, C. Sevonius, P. Salminen, D. Lindberg, A. Brink, P. Yrjas, L. Hupa, Defluidization of the oxygen carrier ilmenite- Laboratory experiments with potassium salts, Energy 148 (2018) 930-940. ISSN: 0360-5442 Elsevier

J-E. Eriksson, A. Brink, M. Zevenhoven, P. Yrjas, L. Hupa, Effect of potassium-enriched ilmenite bed particles on corrosion of heat transfer materials in chemical looping combustion, Nordic Flame Days 2017, 10-11 October 2017, Stockholm, Sweden

J.-E. Eriksson, A. Brink, M. Zevenhoven, P. Yrjas, L. Hupa, Effect of potassium-enriched ilmenite bed particles on corrosion of heat transfer materials in chemical looping combustion, to be presented on the 5th International Conference on Chemical Looping, 24-27 September 2018, The Chateaux at Deer Valley, Park City, Utah

Øyvind LANGØRGEN and Inge SAANUM, SINTEF Energy Research. Chemical Looping Combustion of wood pellets in a 150 kW_{th} CLC reactor. Article and Oral presentation at the 1st International Conference on Negative CO_2 Emissions (May 22-24, Gothenburg):

Accepted for oral presentation at the 5th International Conference on Chemical Looping (September 24-27, Utah):

CHEMICAL LOOPING COMBUSTION OF BIOMASS PELLETS IN A 150 kWth CLC REACTOR.
Øyvind LANGØRGEN, Inge SAANUM, Nils Erland HAUGEN, SINTEF Energy Research.

Malin Hanning, Angelica Corcoran, Fredrik Lind, Magnus Rydén. Biomass Ash Interactions of a Manganese Ore Used as Oxygen-Carrying Bed Material in a 12 MWth CFB Boiler. 2017 submitted to: Biomass and bioenergy

Tomi Thomasson, Janne Kärki, Toni Pikkarainen, Eemeli Tsupari. Techno-economic analysis of bio-CLC: the effect of negative emissions. submitted to: International Journal of Greenhouse Gas Control

E. Eriksson, A. Brink, M. Zevenhoven, P. Yrjas, L. Hupa. Effect of potassium-enriched ilmenite bed particles on corrosion of heat transfer materials in chemical looping combustion. Nordic Flame days, 10-11 October 2017, Stockholm

'Sustainable Energy Systems- Smarter, Integrated and CO2-Negative' side event held on May 24th as part of the Nordic Clean Energy Week in Copenhagen and Malmö. Side event was hosted by Aalborg University in Copenhagen. The following presentations were held by project partners:

Oral presentations at the Nordic Clean Energy Week side event at Aalborg University, Copenhagen, May 24th, 2018
Are Negative Emissions Needed to meet Climate Targets Decided?
- Keith Whiriskey, Project Manager at Bellona Europe

Negative CO2 emissions in the Nordic energy systems, perspectives towards 2060
- Tomi Lindroos, VTT

Why can the Cost of CO_2 Capture Be Dramatically Reduced with Chemical-Looping Combustion?
- Magnus Rydén, Chalmers

Chemical-Looping Combustion of Biomass – Operation in Three Pilot Units
- Øyvind Langørgen, SINTEF Energy

10 MW boiler tests: conclusions
– Magnus Rydén, Chalmers

IEA taskforce 41: presentation held by Keith Whiriskey, 16.01.2018

Other Outreach activities

Bellona CCS forum, Oslo, December 7th

- Kulturhuset, Oslo
- Nordic cooperation, Swedish climate goals negative emissions, role for Bio-CCS
- User groups: Industry, public sector, academia, NGOs
- 70 participants
- Link: (English) http://bellona.org/news/ccs/2017-12-24303, (Norwegian) http://bellona.no/nyheter/co2-fangst-og-lagring/2017-12-19786
- Video, livestream, Debate in Norwegian radio channel P2
- Results:
  - Nordic dialogue, also on the political level
  - Publicity for negative emissions
  - Meeting opportunities

Highlighted results of this seminar include:
Increased awareness of the need and potential for Nordic cooperation with regards to the establishment of a common CCS infrastructure; awareness of the need for negative emissions technologies, and the potential for CCS on facilities utilizing biomass (e.g. waste incineration); and the opportunity to emphasize broad political agreement between Swedish and Norwegian politicians, that negative emissions and CCS are required in order to reach their climate goals.

Bellona CCS Forum, Oslo, January 16th

- Kulturhuset, Oslo
- Cement and waste, negative emissions
- 29 participants
- User groups: Industry, public sector, academia, NGOs
- Link:http://bellona.no/nyheter/co2-fangst-og-lagring/2018-01-norsk-svensk-co2-samarbeid

Highlighted results of this seminar include:
Presentation of regional, cross-border cooperation opportunities; increased contacts between industrial and political actors from Gothenburg and Oslo; presentation of the climate goals of Gothenburg and Oslo, and the role of negative emissions; and the presentation of the potential for further concrete CCS cooperation between the two cities in the waste and cement industries.

COP23, Bonn, November 2017
Bellona organized a number of events during the UN Climate Summit COP23. Four of these had a direct relevance to the Negative CO_2 project.
Link: http://bellona.no/nyheter/klima/klimatoppmoter/2017-11-bellona-pa-klimatoppmotet

- «CCS indispensable for reaching climate targets»
  - Seminar, 06 November 2017, EU Pavilion, COP23, Bonn
  - Role of CCS in the European process industry
  - 20 participants
  - User groups: Industry, public sector, academia, NGOs

- «Green public procurement in practice: Demand and supply of low-carbon building materials and transportation»
  - Seminar 07 November 2017, Nordic Pavilion, COP23, Bonn
  - Public procurement of low-carbon building materials, bio-CCS
  - 20 participants
  - User groups: Industry, public sector, academia, NGOs

- «CCS developments towards a 1.5°C World: Will it help the oceans and small developing islands? »
  - Seminar, 07 November 2017, Bonn Zone, COP23, Bonn
  - Need for CCS in order to reach climate targets, negative emissions
  - Ca. 100 participants
  - User groups: Industry, public sector, academia, NGOs

- «Greenhouse gas mitigation in the waste sector with composting, enhanced MRV systems, and CO2 capture»
  - Seminar 11 November 2017, Bonn Zone, COP23, Bonn
  - Need for CCS in order to reach climate targets, negative emissions
  - Ca. 100 participants

- User groups: Industry, public sector, academia, NGOs

- In addition to events and presentations, Bellona was also available for questions and information at a stand in the Bonn Zone. This stand was used both by the University of Texas, Bellona, as well as other stakeholders.

Media Coverage

Newspaper, radio, web, magazine articles

Olav Øye and Gøril Tjetland, editorial in Fredrikstad blad: https://www.f-b.no/ora/frevar/borg-havn/fredrikstad-kan-bli-pion-r-i-karbonfangst-og-lagring/s/5-59-990194?key=2018-01-16T11:59:48.000Z/retriever/cf41926d8427e4bf96f76c956370fff4d1e10122

Olav Øye, editorial in Aftenposten. 'Transportøkonomisk Institutt skaper unødig forvirring'. 14.01.2018. Response to an article in one of Norway's main newspapers claiming that vehicles running on fuels from captured industrial CO2 is a major step in reaching the global climate goals. However, not only are fully electric vehicles necessary, negative CO2 emissions are required.
https://www.aftenposten.no/meninger/debatt/i/l1z4p7/Transportokonomisk-Institutt-skaper-unodig-forvirring--Olav-Oye

Gøril Tjetland. 'Jo, CO2-rensing er nødvendig'. 15.01.2018. Editorial in the Dagsavisen paper in Norway.

https://www.dagsavisen.no/nyemeninger/jo-co2-rensing-er-n%C3%B8dvendig-1.1083644

Lyngfelt, Anders; Thore Berntsson; Mathias Fridahl; Filip Johnsson; Markus Larsson; Jan Pettersson och Elisabeth Undén. Sverige behöver en strategi för negativa utsläpp, Aktuell Hållbarhet. 2017-10-19. Aktuell Hållbarhet
https://www.aktuellhallbarhet.se/sverige-behover-en-strategi-negativa-utslapp/

Anders Lyngfelt, Elisabeth Undén, Mathias Fridahl, Filip Johnsson, Jan Pettersson, Thore Berntsson, Markus Larsson. Dagens Nyheter Debatt. "Så kan framtidens flygresor rädda klimatet", April 19, 2018. https://www.dn.se/debatt/sa-kan-framtidens-flygresor-radda-klimatet/

Maria Gunther. Dagens Nyheter. ”Vi måste tvätta bort koldioxid ur atmosfären”, May 20, 2018. Portrait of negative CO2 emissions, with quotes from Anders Lyngfelt. https://www.dn.se/arkiv/nyheter/vi-maste-tvatta-bort-koldioxid-ur-atmosfaren/

Lyngfelt, Anders; Thore Berntsson; Mathias Fridahl; Filip Johnsson; Markus Larsson; Jan Pettersson och Elisabeth Undén. Repliker. Dagens Nyheter Debatt. ”Tekniken för infångning och lagring av koldioxid finns och används”, April 26, 2018. https://www.dn.se/debatt/repliker/tekniken-for-infangning-och-lagring-av-koldioxid-finns-och-anvands/

Radio

- Dagsnytt 18
  - NRK Radio, 16.10.2016
  - https://radio.nrk.no/serie/dagsnytt-atten/NMAG03020617/16-10-2017#t=00h30m35s

- Debatt i P2
  - NRK Radio, 11.12.2017
  - https://radio.nrk.no/serie/debatt/KMTE83006917/11-12-2017

Flagship Project website

- Article: http://www.nordicenergy.org/article/myths-and-facts-about-negative-emissions/
- Article: http://www.nordicenergy.org/article/making-sweden-carbon-negative-by-2045/
- Article: http://www.nordicenergy.org/article/chemical-looping-combustion-gains-momentum-in-the-eu/
- Article: http://www.nordicenergy.org/article/annual-public-workshop-2017-at-the-parliament-of-sweden/
- Article: http://www.nordicenergy.org/article/significant-progress-on-chemical-looping-combustion-of-biomass/

M.Sc. thesis

Patrik Salminen. The interaction between potassium salts and bed materials in chemical looping combustion under oxidizing conditions. 2017. Published in / submitted to: Åbo Akademi University

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Upcoming events

5th International Conference on Chemical Looping
Where: Utah, USA
When: September 24-27, 2018

Flame Days, Finnish National Committee of the International Flame Research Foundation
Where: Espoo, Finland
When: October 23rd
This flagship project plans a side-event in connection with the Flame Days conference.

GHGT-14
Where: Melbourne, Australia
When: October 21-26

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

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