Negative CO_2

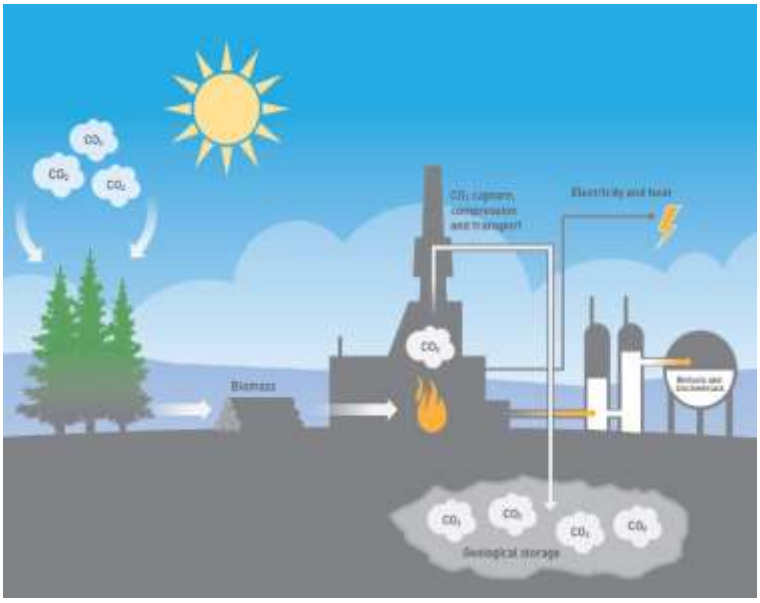
Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

Negative CO_2 newsletter #2
1 September 2016

The Nordic Energy Research Flagship Project "**Negative CO_2 Emissions with Chemical Looping Combustion of Biomass**" has set sail, cruising purposefully towards the future shores of negative CO_2 emissions. This is the second newsletter of the project. The newsletter is public and will briefly summarize research progress and news related to the project. The newsletter also includes a brief introduction.

The *Paris Agreement* adopted by consensus on 12th of December 2015 within the framework of the United Nations Framework Convention on Climate Change stipulates that the increase in the global average temperature should be limited to well below 2°C above pre-industrial levels, and pursue efforts to limit the temperature increase to 1.5 °C. In order to meet this target there is a remaining CO_2 budget corresponding to less than thirty years (for 2°C) or as little as ten years (for 1.5°C) of today's emissions. In practice, these stringent emission limits means that technology capable of generating negative CO_2 emissions will need to be developed and deployed in grand scale in the coming decades.

Biomass is a renewable energy source that extracts CO_2 from the atmosphere during its growth. It is affordable and widely available and the Nordic countries are world leading in biomass utilization. If CO_2 generated during biomass combustion is captured and brought to a geological storage, the result will be a net decrease of CO_2 in the atmosphere (see figure). The concept is referred to as **Bio-Energy with Carbon Capture and Storage** (BECCS) and offers a very realistic method for effectively removing carbon dioxide from the atmosphere, making also the most ambitious CO_2 targets achievable.



Schematic description of BECCS (illustration by Doghouse.no/SINTEF).

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The ultimate goal of the Negative CO_2 project is the development of new competitive technology that:

- enables CO_2 capture and negative CO_2 emissions with the lowest possible cost and energy penalty
- is able to produce power and/or steam for industrial and other applications
- utilizes Nordic expertise and competence in fluidized bed technology
- eliminates thermal NO_x emissions and has potential to achieve more efficient fuel utilization compared to ordinary biomass combustion.

The technology capable of achieving these goals is **Chemical-Looping Combustion of biomass (Bio-CLC)**, a unique and innovative combustion technology that will be studied and developed in the project. Chemical-Looping Combustion (CLC) involves oxidation of fuels with oxygen provided with solid oxygen carrier particles rather than with air and both the high energy penalty and the high capital cost associated with gas separation can be avoided. Because of this CLC is expected to have at least 50% lower energy penalty and cost than any other CO_2 capture technology.

Project news (March 2016 – August 2016)

Project website launched

The project website is now launched at: http://www.nordicenergy.org/flagship/negative-co2/

Scientific and technical progress

During the first project period several key decisions was taken with respect to reference fuels (Finnish White Wood Pellets and Norwegian steam treated Arbapellets) and potential oxygen carriers (four manganese ores and four ilmenites available via project partners and members in the project Advisory Board). Key experiments were also performed such as a 3 day campaign in Chalmers Research Boiler/Gasifier and successful commissioning of VTT's 50 kW_{th} scale bio-CLC test rig. In this project period research has firmly gotten started in all project areas:

- ***Pilot plant operation.*** First experimental campaign in VTT's 50 kW_{th} bio-CLC test rig using ilmenite as oxygen carrier and both reference fuels have been successfully concluded. Preliminary experiments with Arbapellets have been performed in Chalmers 100 kW_{th} CLC reactor, successfully demonstrating biomass feeding and high fuel conversion in the unit. The commissioning of SINTEF's CLC reactor is ongoing (see "other project-related news" below).
- ***Investigation and characterization of Oxygen Carrier materials.*** First batch of oxygen carrier materials provided by organizations associated with the project are currently being examined by SINTEF.
- ***Interaction between oxygen carrier particles and ash components.*** Experimental work with impregnation of potential oxygen carriers with ash components is ongoing at Åbo Akademi and Chalmers. Two student projects have been finished at Chalmers within the area. At Åbo Akademi 2 student projects are ongoing. A collaborative student project between Åbo Akademi and Chalmers is planned. At Åbo Akademi ilmenite has been studied with respect

to agglomeration tendencies when interacting with ash compounds. Further work has been done at Chalmers with respect to manganese ore used in Chalmers Research Boiler/Gasifier.

- ***Oxygen carrier preparation in large scale.*** Large scale preparation (several tons) of oxygen carriers based on manganese ore are being carried out by Chalmers and Sibelco. This material will be used in Chalmers 100 kW pilot plant and possibly in other units or Chalmers Research Boiler.
- ***O_2 polishing and flue gas cleaning.*** Successful experiments have been performed with O_2 polishing in Chalmers 100 kW CLC unit, using a basic post oxidation chamber. Also a sub-project about modelling of O_2 polishing has been launched and is currently ongoing.
- ***Design and techno-economic analysis of Bio-CLC plant.*** Fundamental design and analysis initiated by VTT and Chalmers.
- ***Bio-CLC in a low-carbon Nordic energy system.*** Preliminary examination and first report with simplified cost and performance data has been compiled by VTT in cooperation with Chalmers.

In short, work has been successfully initiated and is proceeding as planned in all areas. This bodes well for the execution of the project and should result in important publications coming periods.

Highlighted result:

From: *Berdugo Vilches T, Lind F, Thunman H, Rydén M. Experience of more than 1000h of operation with oxygen carriers and solid biomass at large scale. 4th International Conference on Chemical Looping in Nanjing, China*.

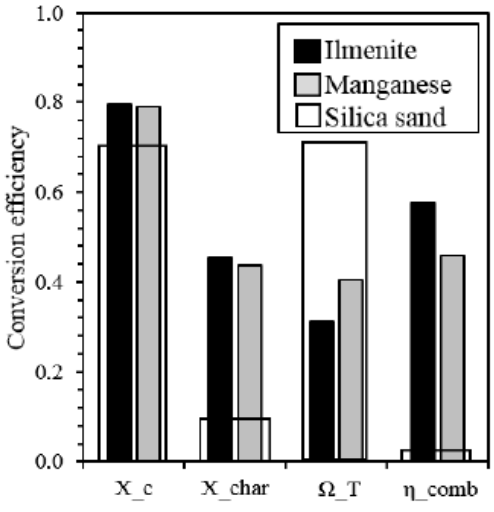

Figure 5. Oxygen demand (Ω_T), combustion efficience (η_{comb}), carbon conversion (X_c), and char conversion (X_{char}) for ilmentie, manganese and the reference case with silica sand. Bed temperature 830°C

The figure demonstrates that simply changing from silica sand to an oxygen carrying bed material (ilmenite, manganese ore) in a semi-industrial circulating fluidized bed boiler/gasifier alters the product composition in the gasification reactor completely. Basically, the gasification reactor turns into a "fuel reactor" in what could be described as a "pseudo-CLC plant". The combustion efficiency (η_{comb}) is up to 60% already at 830°C, or up to 70% if char is discarded ($1-\Omega_T$). The article shows that this has now been demonstrated at MW-scale over extended time periods. By improving fuel feeding (the gasifier used is top-fed), fuel reactor design and increasing fuel reactor temperature, the project consortium believed that fuel conversion well above 90% could be achieved in dedicated future Bio-CLC plants. This remains to be demonstrated within the project.

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Dissemination to the scientific community

The following presentations will be held during the autumn:

- *Rydén M, Lyngfelt A, Langørgen Ø, Larring Y, Brink A, Teir S, Havåg H, Karmhagen P. Negative CO_2 Emissions with Chemical Looping Combustion of Biomass – a Nordic Energy Research Flagship Project.* Oral presentation to be held on November 16 on the 13th Conference on Greenhouse Gas Control Technologies in Lausanne, Switzerland.
- *Hanning M, Corcoran A, Zhao D, Lind F, Rydén M. Characterization of Oxygen Carriers during Combustion and CLC Conditions in a 12 MW_{th} Circulating Fluidized Bed Biomass Boiler.* Oral presentation to be held on September 26 on the 4th International Conference on Chemical Looping in Nanjing, China.
- *Berdugo Vilches T, Lind F, Thunman H, Rydén M. Experience of more than 1000h of operation with oxygen carriers and solid biomass at large scale.* Oral presentation to be held on September 27 on the the 4th International Conference on Chemical Looping in Nanjing, China.
- *Pikkarainen T, Hiltunen I, Teir S. Piloting of BIO-CLC for BECCS.* Oral presentation to be held on September 28 on the 4th International Conference on Chemical Looping in Nanjing, China.
- *Lagerbom J, Pikkarainen T. Chemical Cycling Testing of Fe_2O_3-Al_2O_3 Oxygen Carrier for Chemical Looping Combustion.* Oral presentation to be held on September 28 on the 4th International Conference on Chemical Looping in Nanjing, China.
- *Rydén M, Thunman H, Lind F, Lyngfelt A. About the use of Circulating Fluidized Bed (CFB) boilers for demonstration of Chemical Looping Combustion (CLC).* Oral presentation to be held on September 26 on the 4th International Conference on Chemical Looping in Nanjing, China.
- *Zevenhoven M, Lindberg D, Brink A, Hupa L, Smått J-H, Kronlund D, Rydén M, Lyngfelt A, Lagerbom J, Langorgen O, Larring Y. Chemical looping combustion of biomass– Interaction of ash forming matter with bed material.* To be presented to the 2016 International Conference of the Impact of Fuel Quality on Power Production and the Environment in Prague, Czech Republic, 19-23.9.2016.
- *Arasto A, Tsupari E, Pikkarainen T, Kärki J, Tähtinen M, Sormunen R, Korpinen T. Achieving Negative Emissions with the most Promising Business Case for BIO-CCS in Power and CHP Production.* Poster to be presented on the 13th Conference on Greenhouse Gas Control Technologies in Lausanne, Switzerland.

Other dissemination

- *Robin Sanharib Deniz. Theoretical calculation and experimental evaluation of interactions between ash and oxygen carriers in Chemical-Looping Combustion - K, Ca, Si and Fe_2O_3, Mn_3O_4 and synthesized ilmenite . Master's thesis in Innovative and Sustainable Chemical Engineering, Chalmers University of Technology.*
- *Viktor Andersson, Ivana Stanicic, Sofie Ek, Azra Vilic, Christoffer Sellgren, William Svärdström. Interaktion mellan syreb□rare och aska. Bachelor's thesis in Innovative and Sustainable Chemical Engineering, Chalmers University of Technology.*

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About Negative CO2

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

Public awareness

- Anders Lyngfelt of Chalmers is interviewed about Negative CO_2 emissions and Chemical-Looping Combustion in the weekly Swedish engineering journal Ny Teknik, 20 April 2016. http://www.nyteknik.se/energi/chalmers-falla-fangar-gamla-koldioxidsynder-6542475
- Magnus Rydén of Chalmers is interviewed about Negative CO_2 emissions and Chemical-Looping Combustion in the monthly Swedish popular science journal Forskning och Framsteg (issue 5-2016). http://fof.se/tidning/2016/5/artikel/sa-ska-koldioxiden-sugas-tillbaka
- Magnus Rydén of Chalmers is interviewed about Negative CO_2 emissions and Chemical-Looping Combustion in the Swedish daily newspaper Göteborgsposten (Sunday 29/5, www.gp.se).
- Magnus Rydén of Chalmers is interviewed about Negative CO_2 emissions and Chemical-Looping Combustion in the Swedish trade magazine Fjärrvärmetidningen (www.svenskfjarrvarme.se).

Beyond the science news

- Bellona hosted a Bio-CCS forum in Oslo 31 March. Speakers included representatives from the Norwegian climate research center CICERO, Bellona Europa, Carbon Clean Solutions and the Norwegian Parliament.
- On 4 July the Norwegian government presented its feasibility studies for CCS alternatives in Norway. An English summary of the study is available online here.
- Bellona commented on the Norwegian CCS progress in Politico on 1 July. Bio-CCS at Klemetsrud in Oslo was highlighted in the article.
- On 11 and 12 May Bellona hosted the IEA Bioenergy group's workshop on Bio-CC(U)S in Oslo. This visit was covered by one of the largest Norwegian newspapers on 12 May (for Norwegian readers).

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Other project-related news

New advisory board member. A new partner has been recruited to the advisory board of the project: *Fores* is a Swedish green liberal think tank with interest in Carbon Capture and Storage.

First successful CLC operation of the 150 kW pilot plant at SINTEF.
In June, the 150 kW_{th} CLC pilot plant at SINTEF in Trondheim achieved its first successful operation in full CLC mode with very good results. Methane was used as fuel and copper oxide based particles were used as oxygen carrier. At a fuel power of 100 kW, methane conversion of up to 98% was obtained. This was achieved at a rather low specific fuel reactor oxygen carrier inventory of 100 – 120 kg/MW. The SINTEF pilot plant has been built and commissioned through the Centre for Environment-Friendly Energy Research "BIGCCS" while the oxygen carriers have been provided through the EU FP7 project "SUCCESS". When the tests agreed in these projects are finalized this autumn the pilot plant will be supplemented with a biomass fuel feeding system and made ready for tests within the Nordic Energy Research funded project "Negative CO_2". The first successful CLC operation is therefore also a milestone with respect to development of Bio-CCS using CLC technology, being the main objective of the "Negative CO2" project.

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

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