BioCarbUp – Optimising the biocarbon value chain for a sustainable metallurgical industry

Newsletter 1-2021

Progress in 2021

In 2021 the focus on studies connected to the resource base in Norway for biocarbon production continues, carbonization experiments have continued in different experimental setups and increasing efforts are directed towards characterization and upgrading of the biocarbons and by-products. The characterization includes physio-chemical and mechanical properties and biocarbon CO_2 reactivity testing, and a summer job student is working at SINTEF Energy Research connected to these topics and kinetics. Characterization methods and critical biocarbon characteristics with respect to the specific biocarbon end-uses have been evaluated and there has been a focus on how to improve biocarbon characteristics by tuning biocarbon production processes and by biocarbon upgrading. The latter is also investigated by the BioCarbUp postdoc candidate. In addition the utilization of the bio-oil from biocarbon production as binder in anode baking has been in focus. The BioCarbUp PhD student continues the work focusing on modelling related to the biocarbon production process. In general, the scientific activities are progressing rather well considering that the Covid-19 situation has inflicted on the progress of experimental activities.

BioCarbUp workshop and steering committee meeting by web

The third BioCarbUp workshop and steering committee meeting was arranged 10-11 March 2021 online. Results and progress were presented, and the program included ample time for discussions with the industry partners regarding the progress of the different project activities.

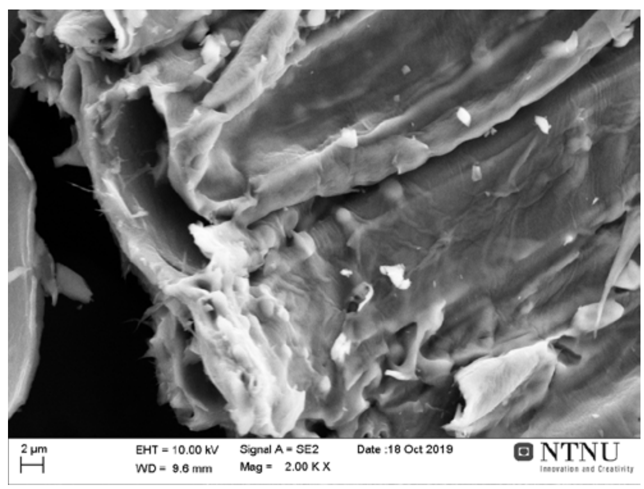
PostDoc work

The BioCarbUp PostDoc work within composite agglomerates with biocarbon is progressing well. The PostDoc candidate, Hamideh Kaffash from Iran, started her work August 2019 at Department of Materials Science and Engineering, NTNU, with Professor Merete Tangstad as her supervisor.

Some very interesting recent results:
Three types of industrial charcoal have been densified using C from CH_4 and the C deposition was found to be 13-15%. The properties of the charcoals before and after densification by C deposition were investigated, with the following results:

1. Density increased by 7-18%
2. Porosity decreased by 23-38%
3. Compressive strength increased very much (results to be published)
4. CO_2 reactivity decreased by 28-35%

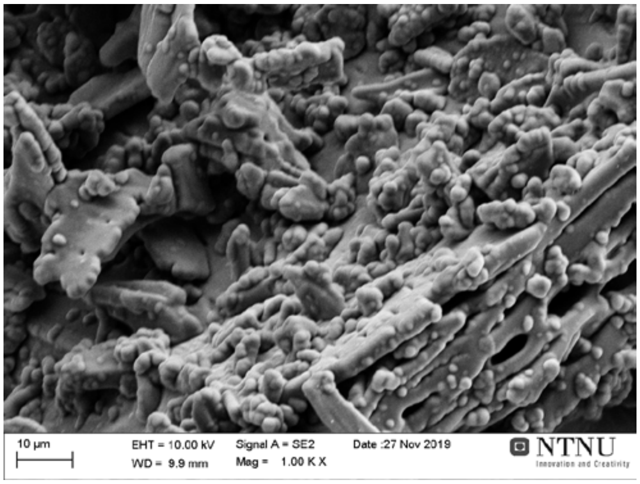
These are promising results, making charcoal more suitable for use in some metallurgical industries. Below are pictures showing a charcoal surface before and after deposition of C from CH_4.



Charcoal before deposition of C from CH_4

- a Knowledge-building Project for Industry (KPN) co-funded by
the Research Council of Norway through the ENERGIX-programme.
Contact: oyvind.skreiberg@sintef.no

SINTEF



Charcoal after deposition of C from CH_4

See the publication Densification of Biocarbon and Its Effect on CO_2 Reactivity for further information.

Charcoals have also been impregnated with K to see how the CO_2 reactivity changes and it was found that with increasing K content in the charcoal of up to 2%, the CO_2 reactivity increased slightly, by a factor of 2, while we know from other works that for coke it increased by a factor of 10. A manuscript has now been submitted on the CO_2 gasification of densified biomass and the influence of K on the reaction rate.

Recently, densification experiments with a very different charcoal (compared to the 3 types of charcoal earlier tested) from South Africa were carried out to see if one could get the same good results. Results analyses are in progress.

Two summer master students who the PostDoc candidate is co-supervising together with Merete Tangstad are now working on densification of biocarbon and its characterization. This is a joint undertaking with the KPN Reduced CO_2 project.

PhD work

The BioCarbUp PhD position within Modelling and CFD simulation of pyrolysis reactors has been filled. The candidate, Boyao Wang from China, is employed at Department of Energy and Process Engineering, NTNU, with Professor Terese Løvås as supervisor and Adjunct Associate Professor Tian Li as co-supervisor. The candidate will focus on numerical modelling and simulation for efficient biocarbon production. Mandatory course work, literature review and initial research activities are ongoing.
Additionally, Boyao joined the ePYRO 2021 conference and presented the work of the PhD project. Different pyrolysis kinetic schemes have been compared and it was found that most of the kinetic schemes do not consider the secondary charring process. However, the secondary charring has noticeable effects on the char yield. Therefore, the investigation of the secondary charring processes will be in focus in the further work.

SP1 (Biocarbon resources and value chain for metallurgical industry) work

In this spring BioCarbUp did a survey on the biggest wood chip suppliers in Norway. The main purpose of the survey was to investigate the quality of the wood chips delivered to the heating plants and challenges regarding supply of chips.
In the survey the chip suppliers were asked about the following quality parameters:

- Moisture content
- Bulk density
- Amount of fines
- Amount of ash
- Content of nitrogen
- Wood species
- Storage time

Many of the quality parameters for wood delivered to heating purposes, will be the same for chips delivered for biocarbon production, except for fines. On the new biocarbon factory operated by Oplandske Bioenergi on Rudshøgda it is said that the amount of fines is not a problem. This is good news for using more grot, since chips produced from grot contents a lot of fines!
All the chip suppliers had the moisture content as the most important quality parameter. The second most important quality parameter was the amount of fines. Fines are defined as particles smaller than 3.15 mm. If the amount of fines is more than 20 %, it is a problem in many heating plants in Norway.
Bulk density of the chips was also an important issue. Too low density means reduced heat production. The density in the wood chips depends both on the specific density of the wood and the solid volume fraction in the chips.
Traceability of the wood is getting more and more important. About 80 % of the respondents had good traceability of the wood. Most of the chip suppliers had good overview of the wood logistics.
In general, the survey shows that the suppliers of the chips have good knowledge about the quality, volume and traceability.

Chipping of the whole tree. Photo by Eirik Nordhagen

SP2 (Biocarbon production and upgrading) work

Test of gasification reactivity of different biocarbons in a Macro-TGA

When used in metal production processes, biocarbon will be fed into high temperature conditions with presence of different gases. Hence, it is necessary to understand changes in biocarbon properties and reactivity under these conditions. Four kinds of biocarbons produced from different feedstocks in the SINTEF Energy Research lab in Trondheim were tested in a Macro-TGA in the SINTEF Industry lab in Trondheim in 50% CO and 50% CO_2 atmosphere. Figure 1 shows the weight loss behaviours of the four biocarbons as a function of conversion time. The weight loss caused in the devolatilization stage in N_2 atmosphere when heating the sample from room temperature to 1100 °C with 30 minutes holding time at this temperature is omitted. Therefore, Figure 1 displays only the gasification behaviour of the highly carbonized samples. It can be clearly seen that the carbonized pellets react much slower compared to the carbonized birch wood chips, and that the type of pellet and the carbonization conditions also influence. The gasification reactivity of biocarbon derived from different carbonaceous materials is influenced by their physical and chemical properties. Figure 2 shows that the carbonized steam exploded pellet has very compact structure and intact surface. On the contrary, the carbonized birch wood chip has a clear cellular structure with large openings, indicating larger pore volume and surface area in comparison to the carbonized steam exploded pellet. It can partially explain the high gasification reactivity of the carbonized birch wood chip compared to that of the carbonized steam exploded pellet. Figure 3 shows SEM analysis on the presence of inorganic elements in the residues collected after the Macro-TGA tests. Figure 3 (top) shows aggregated and sintered particles with light bright colour on the surface of the residues from the gasified carbonized birch wood chip. Ca, Fe, Mg and P were detected by EDS as main inorganic elements in these particles. On the other hand, such particles were not observed on the surface of the residues from the gasified carbonized steam exploded pellet. These inorganic elements have considerable catalytic effects on carbon gasification and the presence of them in the birch wood biocarbon can partially explain the higher conversion degree of the biocarbon at a given time compared to the steam exploded pellet, in addition to the differences in pore volume and surface area.

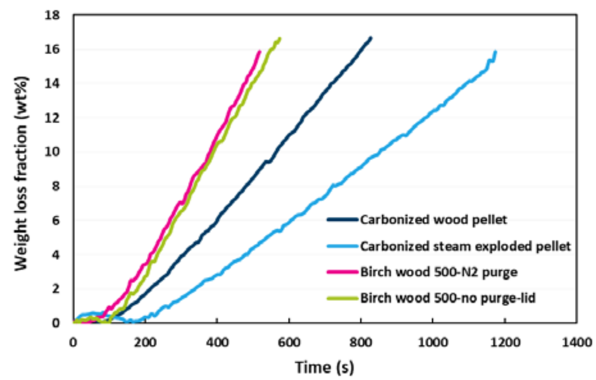


Figure 1. Gasification behaviour of different biocarbon samples in 50% CO and 50% CO_2 atmosphere at 1100 °C

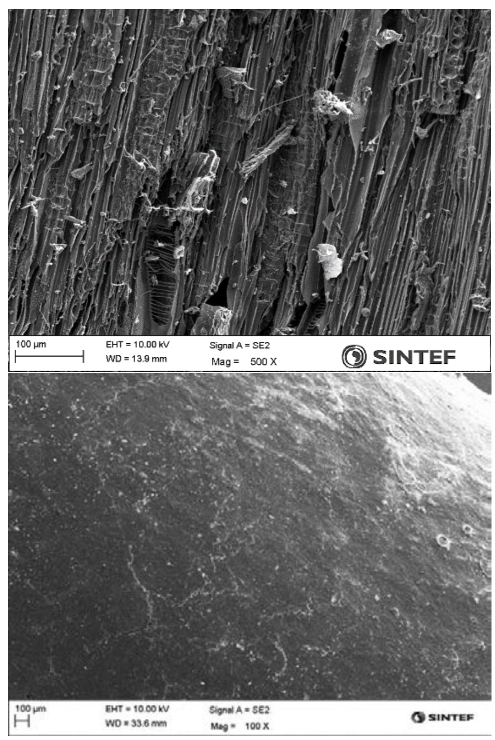


Figure 2. SEM images of carbonized birch wood chip (top) and carbonized steam exploded pellet (bottom)

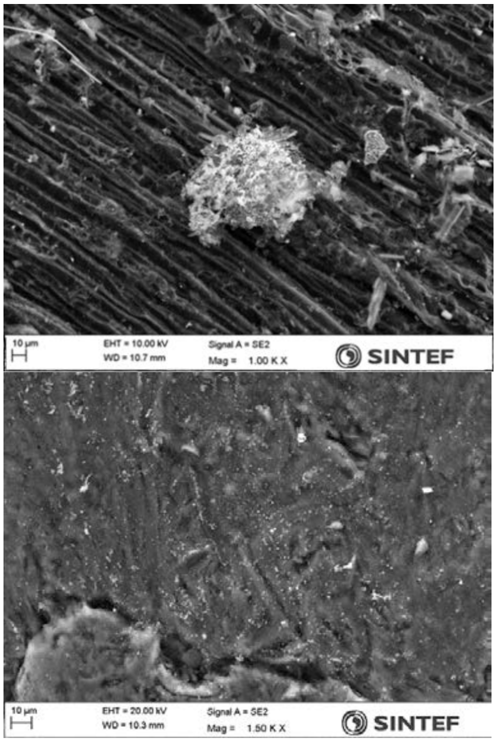


Figure 3. SEM images of carbonized birch wood chip (top) and carbonized steam exploded pellet (bottom) after further devolatilisation followed by gasification at 1100 °C in 50% CO and 50% CO_2 atmosphere until about 20% fixed carbon remains

Characterization of the volatiles from biocarbon produced at different conditions

Volatile matter content is one of the critical properties of biocarbon, which are considerably affected by the type and characteristics of the feedstock, production process conditions, post treatment etc. The amount and type of volatile matter is of importance for metal production processes, for stability and quality of operation and gas handling and cleaning. In SP2, evolution profiles of volatiles of biocarbon produced at different conditions were characterized at the Hungarian Academy of Sciences by thermogravimetry/mass spectrometry, see Figure 4 and 5. The amount and the evolution profiles of the main gaseous products were similar from spruce and birch biocarbons prepared under the same conditions. On the other hand, different evaluation behaviours of methane, water, and carbon monoxide were observed from biocarbons produced at low (Figure 4) and high (Figure 5) temperatures.

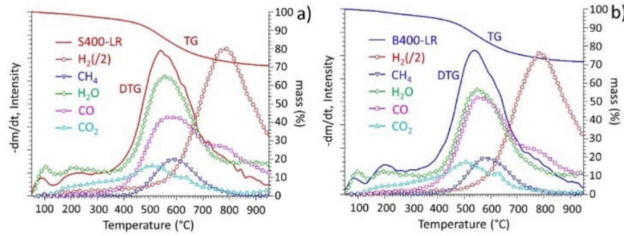


Figure 4. TG, DTG and evolution profiles of main gases from spruce (a) and birch (b) biocarbons produced at 400 °C, measured up to 950 °C

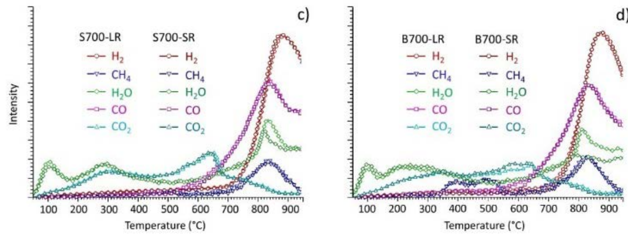


Figure 5. Evolution profiles of main gases from spruce (c) and birch (d) biocarbons produced at 700 °C, measured up to 950 °C

BioCarbUp summer student

A summer student financed by BioCarbUp within the SINTEF summer job program is working with aspects connected to biocarbon mechanical properties and gasification reactivity. The summer job is carried out in the SINTEF Energy Research lab in Trondheim through using a combination of different testing facilities (i.e., tumbler and hardness tester, for testing abrasive and mechanical strength). The primary objective is to investigate and compare the mechanical properties of biocarbon produced from different feedstocks and under different conditions. The secondary objective is to assess the CO_2 reactivity of these biocarbons and correlate it to their physio-chemical properties.

SP3 (Biocarbon end-use) work

Successful meetings between the researchers at Laval University and SINTEF Industry with respect to bio-pitches for anodes in aluminium production has been held this spring. New and exciting results were shared and specific collaborations were suggested. The talks resulted in produced binder materials from both institutions being shared for comparison this summer, and anode materials based on bio-pitches being sent to SINTEF for supplementary imaging techniques to confirm the good results of the pilot anodes made at Laval.

Preparation for the ICSOBA 2021 hybrid-conference (https://icsoba.org/upcoming-icsoba-event-2021/) is underway, and a paper for the conference proceeding based on the initial results on bio-binders from BioCarbUp is being prepared. The plan from the organizers is to promote biocarbon on this platform and make it one of the potential game changing topics, making this a good conference to present results from the project.

Change of BioCarbUp SP3 leader

Research Scientist Gøril Jahrsengene has replaced Eli Ringdalen as leader of SP3 Biocarbon end-use use from February 2021.

BioCarbUp at EUBCE 2021

Two BioCarbUp works have been presented at EUBCE 2021, 26-29 April 2021, online:

1) Liang Wang, Øyvind Skreiberg, Zsuzsanna Czégény, Roman Tschentscher, Maria N.P. Olsen, Karl Oskar Pires Bjørgen (2021). Characterization of Liquid By-products from Slow Pyrolysis of Woody Biomass.

2) Liang Wang, Øyvind Skreiberg, Zsuzsanna Czégény, Maria N.P. Olsen, Karl Oskar Pires Bjørgen (2021). Production and Characterization of Biochar from Woody Biomass under Different Pyrolysis Conditions.

BioCarbUp at ePyro2021

Two BioCarbUp works have been presented at ePyro2021, 12-13 April 2021, online:

1) Øyvind Skreiberg, Liang Wang, Zsuzsanna Czégény, Scott Turn (2021). Tuning the pyrolysis process in the direction of satisfying quality demands of metallurgical industries.

2) Boyao Wang, Tian Li, Terese Løvås, Liang Wang, Øyvind Skreiberg (2021). CFD-DEM modelling of biomass pyrolysis using multi-component kinetics mechanism.

BioCarbUp at BSAEH-2021

One BioCarbUp work has been presented at International Conference on Biotechnology for Sustainable Agriculture, Environment and Health, 4-8 April 2021, online:

Zoltán Sebestyén, Bence Babinszki, Janos Bozi, Emma Jakab, Luca Kőhalmi, Liang Wang, Øyvind Skreiberg, Zsuzsanna Czégény (2021). Effect of slow pyrolysis conditions on biocarbon yield and properties: Characterisation of the volatiles.

BioCarbUp at 38th International Symposium on Combustion

One BioCarbUp work has been presented at 38th International Symposium on Combustion, 24-29 January 2021, Adelaide, Australia:

Boyao Wang, Jingyuan Zhang, Terese Løvås, Tian Li (2021). CFD-DEM modeling of biomass pyrolysis in a fixed bed reactor.

BioCarbUp in Processes

One BioCarbUp work has been published in Processes:

Hamideh Kaffash, Gerrit Ralf Surup, Merete Tangstad (2021). Densification of Biocarbon and Its Effect on CO_2 Reactivity. The abstract is given below.

"Charcoal is an interesting reducing agent because it is produced from biomass which is renewable and does not contribute to global warming, provided that there is a balance between the felling of timber and growth of trees. Biocarbon is a promising alternative to fossil reductants for reducing greenhouse gas emissions and increasing sustainability of the metallurgical industry. In comparison to conventional reductants (i.e., petroleum coke, coal and metallurgical coke), charcoal has a low density, low mechanical properties and high CO_2 reactivity, which are undesirable in ferroalloy production. Densification is an efficient way to upgrade biocarbon and improve its undesirable properties. In this study, the deposition of carbon from methane on three types of charcoal has been investigated at 1100 °C. CO_2 reactivity, porosity and density of untreated and densified charcoal were measured, and results were compared to metallurgical coke. Surface morphology of the charcoal samples was investigated by using scanning electron microscopy (SEM). SEM confirmed the presence of a deposited carbon layer on the charcoal. It was found that the CO_2 reactivity and porosity of charcoals decreased during the densification process, approaching that of fossil fuel reductants. However, the CO_2 reactivity kept higher than that of metallurgical coke."

BioCarbUp in Energy

One BioCarbUp connected work has been published in Energy:

Lorenzo Riva, Liang Wang, Giulia Ravenni, Pietro Bartocci, Therese Videm Buø, Øyvind Skreiberg, Francesco Fantozzi, Henrik Kofoed Nielsen (2021). Considerations on factors affecting biocarbon densification behavior based on a multiparameter model. The abstract is given below.

"The optimization of upscaled biochar pelleting is limited by lack of knowledge regarding the effects of process parameters. A multiparameter model, coupled to a single pellet press unit, was for the first time applied to biochar production to predict the upscaled biochar pelleting process behavior. The model permits to estimate in a time and cost-effective way how the die friction forces, quantified through the pellet exiting pressure, are affected by the key process parameters. It was observed that to achieve acceptably low exiting pressures (in the order of 100 MPa), it was critical to produce biochar at high temperatures (e.g. 600 °C). Addition of water as a binder is also beneficial, while pelletization temperature does not significantly affect the exiting pressure. Furthermore, when pyrolysis oil was used as a binder, lower exiting pressures were measured. Biochar returned higher exiting pressure values compared with untreated wood, but lower compared with torrefied wood. Moreover, the correlation between density and compressive strength was also examined. It was found that the exiting pressure trend is a good indicator to estimate the mechanical quality of the pellets."

Other news

Elkem biocarbon production plant in Canada

Elkem has in an press release announced:
"Elkem has decided to invest in a new biocarbon pilot plant in Canada. The project aims to secure industrial verification of Elkem's technology for renewable biocarbon, with a long-term goal of contributing to climate-neutral metal production. The technology also has potential for application in other industry sectors, contributing to reduced CO_2 emissions. The total investment for the pilot plant amounts to NOK 180 million. The project has received financial support from the Canadian government, the Québec government and the city of Saguenay, reducing Elkem's net investment to NOK 60 million. The plant will be constructed near Elkem's production site in Chicoutimi, Quebec, Canada, with start of construction planned for the second half of 2020. Based on conclusions from the pilot, Elkem will evaluate the basis for a full-scale plant."
The erection of the Elkem plant is now in progress.

Prosess21

Prosess21 is a forum established to strengthen the coordination between the competence environments in and connected to the process industry and the public actors. Prosess21 shall give strategic advices and recommendations on how to minimize emissions from the process industry while achieving sustainable growth. The metallurgical industry is a very important part of the Norwegian process industry. Prosess21 provided their input to the work with a Report to the Storting (white paper) regarding how to reach the national climate goals for 2030. An interesting report, with respect to possible future use and priorities regarding biomass based materials in the Norwegian process industry, Biobasert Prosessindustri, is now finalized by one of the Prosess21 expert groups, as well as Ny prosessteknologi med redusert karbonavtrykk inkl. CCU.
For more info about Prosess21:
https://www.prosess21.no/

PhD thesis on Production and application of sustainable metallurgical biochar pellets

Lorenzo Riva, who was awarded the Elkem student prize for 2019 for his work within pyrolysis and pelletization of metallurgical biochar, and his networking abilities, defended his PhD thesis 7 September. He was in his work also collaborating with BioCarbUp. The thesis is available here.

Norsk Biokullnettverk

The "Norwegian Biochar Network" was founded in 2019. Its purpose is to gather actors from the biochar value chains in Norway. The network aims to promote biochar as an important part of the circular economy, and works towards Norwegian leadership in value creation connected to production and utilization of biochar. SINTEF Energy Research is a member in the network, and Øyvind Skreiberg is a member of its board. Also the BioCarbUp industry partners Elkem and Eramet Norway are members in the network. The network has now been in operation for two years and has attracted great interest and many members. As a part of the network activities, seminars, workshops and webinars have been arranged on different biochar topics and for different industries (e.g. the metallurgical industry), and the network also are active in making the biochar voice heard in the society and towards authorities. All in all, the foundation of the network has been a timely one, serving its purpose. For more info about the network: https://www.biokull.info/ and the news page here.

Nordic Biochar Network

The Nordic Biochar Network was founded in 2019. It is a joint initiative of researchers in the Nordic countries to increase and spread knowledge about biochar. Research Scientist Kathrin Weber from SINTEF Energy Research was the main initiator of the Nordic Biochar Network. As a part of the network activities, a conference and webinars have been arranged. For more info about the network: https://www.nordicbiochar.org/

International Biochar Initiative

In addition to the Norwegian Biochar Network and the Nordic Biochar Network, the International Biochar Initiative (IBI) is a source of extensive information connected to the biochar field. Its mission is to provide a platform for fostering stakeholder collaboration, good industry practices, and environmental and ethical standards to support biochar systems that are safe and economically viable. The members of the Norwegian Biochar Network also become members of the international Biochar Initiative. IBI news are available here.

Recent events

Norsk Biokullnettverk seminar for metallurgical industry, 21 January 2021, Arendal, Norway. + virtual

International Symposium on Functional Biomass-derived Carbon Materials (GreenCarbon 2020). 9-11 March 2021, Zaragoza, Spain. e-conference
http://greencarbon-etn.eu/greencarbon2020/

TMS 2021 Annual Meeting & Exhibition, 15-18 March 2021. e-conference
https://www.tms.org/tms2021

International eConference on Analytical and Applied Pyrolysis (ePYRO 2021), 12-13 April 2021. e-conference
http://www.pyro2020.org/

29th European Biomass Conference & Exhibition, 26-29 April 2021, Marseille, France. e-conference
http://www.eubce.com/

Upcoming events

INFACON XVI (The 16th International Ferro-Alloys Conference) - 26-29 September 2021, Trondheim, Norway. hybrid conference
https://www.sintef.no/projectweb/infacon-2021/

23rd International Conference on Analytical and Applied Pyrolysis (PYRO 2022), 15-20 May 2022, Ghent, Belgium.
https://na.eventscloud.com/website/21947/

30th European Biomass Conference & Exhibition, 2022, date and place to be announced.
http://www.eubce.com/

Links (click on the links or logos to get there)

BioCarb+
KPN reduced CO_2
Prosess21
SKOG22
Energi21
Norsk Biokullnettverk
Nordic Biochar Network
International Biochar Initiative

Project information and past achievements

About the project

The overall objective of BioCarbUp is to optimise the biocarbon value chain for the metallurgical industry through:

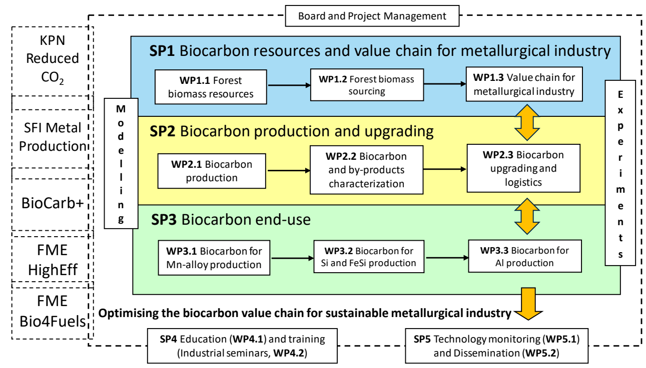
- **Production of biocarbon with sufficient quality** satisfying the end user quality requirements while ensuring optimum utilisation of the by-products
- **Optimised sourcing of Norwegian forest resources** for biocarbon production towards the specific metallurgical processes
- **Maximising the energy and cost efficiency** of the biocarbon value chain for metallurgical industry

The sub-objectives are:

- Identifying **optimum forest resources** for the specific metallurgical processes
- Identifying and **optimizing carbonisation processes and conditions** to produce optimum yields and qualities
- Developing methods for upgrading and **tuning biocarbon quality** to increase its suitability for the specific metallurgical processes, and methods for upgrading the by-product tar to higher value products
- Developing fundamental **knowledge of biocarbon behaviour** in and influence on the specific metallurgical processes and biocarbon impact on product quality
- Increasing expertise throughout the **biocarbon value chain for the metallurgical industry**
- **Educating** highly skilled candidates within this area and training of industry partners
- Monitoring activities and state-of-the-art practice within this area and **disseminating** knowledge to industry partners, and other interested parties where applicable

The anticipated results of the project are reduced harvesting and logistics costs for woody biomass resources, maximised BC yield and quality directly in the BC production process or via secondary upgrading and maximised utilisation in BC end-use applications, i.e. the metallurgical industry. Additionally, by-products utilisation and higher value products from tar are complementary foci.

The Work Breakdown Structure of BioCarbUp is:



BioCarbUP management and work break down structure and project links and information flow.
BioCarb+: Enabling the biocarbon value chain for energy, http://www.sintef.no/biocarb
SFI Metal Production, https://www.ntnu.edu/metpro
FME HighEFF: Centre for an Energy Efficient and Competitive Industry for the Future, http://www.higheff.no
KPN Reduced CO_2 emissions from metal production, https://www.sintef.no/en/projects/reduced-co2-reduced-co2-emissions-in-metal-production/
FME Bio4Fuels, https://www.nmbu.no/bio4fuels

BioCarbUp will run for four years (2019-2022) and has a total cash budget of 25 million NOK, which is 80% financed by the Research Council of Norway through the ENERGIX program and 20% financed by the industrial partners.

The BioCarbUp consortium

The project consortium covers all the necessary aspects, and includes large and central industrial players in the metallurgical and biomass utilization areas in Norway, complemented by recognized international research institutions.

SINTEF Energy Research leads the project and focus on biocarbon production and upgrading and the value chain for metallurgical industry. **NTNU** (Norwegian University of Science and Technology) supervise the PhD, the PostDoc and Master candidates. **SINTEF Industry** focus on biocarbon end-use and bio-based binder. **NIBIO** (Norwegian Institute of Bioeconomy Research) focus on biocarbon resources and value chain for metallurgical industry. **University of Hawaii** focus on biocarbon production at pressurised conditions, while **Hungarian Academy of Sciences** focus on biocarbon and by-products characterization.

The industrial partners contribute with finances as well as access to infrastructure and their extensive industrial knowledge generated through their commercial activities within the metallurgical areas: Elkem, Eramet Norway, Hydro Aluminium, Alcoa Norway, Eyde Cluster, and Norsk Biobrensel as a biomass supplier to metallurgical industry.

The constellation of project partners is very strong, bringing together leading research organisations within the field and major industrial players.

Project background

The ENERGIX program plan clearly states the importance of sustainability and sustainable value chains, including biomass based, contributing to reduced CO_2 emissions and a carbon neutral society in 2050. For biomass, there is an expectation of total biomass feedstock utilisation.

The metallurgical industry in Norway seeks to substitute large amounts of biocarbon for fossil reductants in their processes. The Norwegian Process Industry Roadmap - Combining growth and zero emissions by 2050, and Industrimeldingen lay the foundation for an accelerated utilization of Norwegian biomass resources that would reduce the CO_2 footprint of the metallurgical industry. The former document targets a 43% reduction of CO_2 by 2030 compared to 2005 levels. To enable this transformation, the whole biocarbon (BC) value chain for the metallurgical industry must be optimized to remove economic constraints, satisfy reductant quality demands, and develop predictable (amount, quality and price), long-term biomass resource demand.

This project responds to the national strategies and the goals of the metallurgical industry by analyzing and optimizing the BC value chain to produce suitable and affordable reductants in a sustainable manner. Producing BC, a renewable material from biomass resources, will have a twofold effect: (1) reduce CO_2 emissions by substituting for fossil reductants and (2) increase forest resource utilisation by creating higher value material and/or energy products. Due to the BC quality demanded by the metallurgical processes, woody biomass, especially stem wood, is the most suitable candidate for reductant feedstock.

The overall objective of this project is to optimise the biocarbon value chain for the metallurgical industry.

Project overview

The project is divided into 5 subprojects (SP), each subproject is itself divided into several work packages (WP).

- Biocarbon resources and value chain for metallurgical industry - SP1
- Biocarbon production and upgrading - SP2
- Biocarbon end-use - SP3
- Education and training - SP4
- Technology monitoring and dissemination - SP5

Biocarbon resources and value chain for metallurgical industry - SP1

The main objectives of SP1 are to identify optimum forest resources for the specific metallurgical processes, identify shortcomings in existing biomass quality monitoring systems, and increase the expertise throughout the biocarbon value chain for metallurgical industry.
SP1 leader: Senior Scientific Adviser Simen Gjølsjø, NIBIO

Biocarbon production and upgrading - SP2

The main objectives of SP2 are to develop novel (new) or improved solutions to produce and upgrade biocarbon dedicated for metallurgical processes with optimized logistics and maximize use of by-products.
SP2 leader: Research Scientist Liang Wang, SINTEF Energy Research

Biocarbon end-use - SP3

The main objective of SP3 is to identify biocarbon products that can be used in Mn, Si and Al industry to reduce fossil CO_2 emissions while having neutral or positive impacts on process performance and energy efficiency. SP3 will develop fundamental competence about effect on specific metallurgical processes of changes in properties of carbon sources. Sources currently in use will be compared with bio-based carbon sources.
SP3 leader: Research Scientist Gøril Jahrsengene, SINTEF Industry

Education and training - SP4

The major objective of SP4 is to strengthen the education within this field through MSc and PhD students, and a postdoc candidate. The objective is also to increase the competence level in the industry. The long-term goal is competence building and strengthening of the education within the biocarbon value chain for metallurgical industry.
SP4 leader: Associate Professor Tian Li, NTNU

Technology monitoring and dissemination - SP5

The major objectives of SP5 are to monitor the latest research and technological developments and to disseminate research results.
SP5 leader: Chief Scientist Øyvind Skreiberg, SINTEF Energy Research, who also is the BioCarbUp project leader

Earlier progress

In **2020** the focus on studies connected to the resource base in Norway for biocarbon production continued, carbonization experiments continued in different experimental setups and the biocarbons and by-products were characterized. The characterization included biocarbon CO_2 reactivity testing, and a summer job student was working at SINTEF Energy Research connected to this topic and kinetics. Characterization methods and critical biocarbon characteristics with respect to the specific biocarbon end-uses were evaluated and there was a focus on how to improve biocarbon characteristics by tuning biocarbon production processes and by biocarbon upgrading. The latter is also investigated by the BioCarbUp postdoc candidate. The BioCarbUp PhD student started, focusing on modelling related to the biocarbon production process. In general, the scientific activities were progressing rather well considering that the Covid-19 situation inflicted on the ability to carry out experimental activities, where additional HSE regulations must be followed due to the pandemic.

In **2019** the focus was on start-up of the project, studies connected to the resource base in Norway for biocarbon production, planning and execution of carbonisation experiments, characterisation of biocarbon, start-up of the postdoc work and dissemination from the project.

Earlier publications

BioCarbUp at MIT A+B Applied Energy Symposium

One BioCarbUp associated work was presented at the 2020 MIT A+B Applied Energy Symposium - e-conference, 13-14 August:

Pietro Bartocci, Lorenzo Riva, Henrik Kofoed Nielsen, Qing Yang, Haiping Yang, Øyvind Skreiberg, Liang Wang, Giulio Sorbini, Eid Gul, Marco Barbanera, Francesco Fantozzi (2020). How to produce green coke?

BioCarbUp at EUBCE 2020

One BioCarbUp work was presented at the 28th European Biomass Conference & Exhibition, originally planned for 27-30 April 2020, Marseille, France, but which was changed to an e-conference 6-9 July due to Covid-19:

Liang Wang, Lorenzo Riva, Øyvind Skreiberg, Pietro Bartocci, Henrik Kofoed Nilsen, Francesco Fantozzi (2020). Effect of Pyrolysis Conditions and Use of Condensates as Binder on Densification of Biocarbon.

BioCarbUp in Energy & Fuels

One BioCarbUp work has been published in Energy & Fuels:

Gábor Várhegyi, Liang Wang, Øyvind Skreiberg (2020). Empirical Kinetic Models for the Combustion of Charcoals and Biomasses in the Kinetic Regime. The abstract is given below.

"An empirical kinetic model was proposed in 2019 and tested extensively on biomass pyrolysis (Várhegyi, G., Energy Fuels 2019, 33, 2348−2358). The model was based on an isoconversional kinetic equation. The functions in the kinetic equation were approximated by mathematical formulas with adjustable parameters, and the parameters were determined by the method of least squares. This procedure ensures that the data calculated from the model would be close to the experimental data. In the present work, this way of modeling was adapted for the combustion of charcoals and lignocellulosic biomasses. The performance of the model was tested by the reevaluation of TGA experiments from earlier publications. In total, 18 experiments belonged to a study of charcoals, while 20 experiments were carried out on wheat straw and willow samples. The corresponding temperature programs included linear, modulated, stepwise, and constant reaction rate (CRR) temperature–time functions. The adjustable parameters of the model were determined by the method of least squares by evaluating groups of experiments together. The procedure aimed at finding best-fitting models for the derivative of the measured reacted fraction. The activation energy, E, was regarded as constant for the whole process. The change of the reactivity during the progress of the reaction was described by the rest of the isoconversional kinetic equation. Model variants with different numbers of adjustable parameters resulted in practically identical E values. It was possible to determine common E values for different samples with only a slight worsening of the fit quality. This procedure allowed an easy comparison of the reactivities of the samples as functions of the reacted fraction."

BioCarbUp in Energy & Fuels

One BioCarbUp associated work has been published in Energy & Fuels:

Liang Wang, Lorenzo Riva, Øyvind Skreiberg, Roger Khalil, Pietro Bartocci, Qing Yang, Haiping Yang, Xuebin Wang, Dengyu Chen, Magnus Rudolfsson, Henrik Kofoed Nielsen (2020). Effect of Torrefaction on Properties of Pellets Produced from Woody Biomass. The abstract is given below.

"Torrefaction has been recognized as a promising strategy to improve handling and storage properties of wood-based pellets, thus producing a uniform-quality commodity with high energy density and hydrophobicity. In this work, pellets produced from spruce stem wood, bark, and forest residues were torrefied in a bench-scale tubular reactor at 225 and 275 °C with two residence times (30 and 60 min). The effects of torrefaction on general properties, grindability, mechanical properties, hydrophobicity, and microstructure of the studied pellets were investigated. The increase of torrefaction severity reduced mass yields, but the heating values and the fixed carbon content of the torrefied pellets considerably increased. The grindability of raw pellets was substantially improved after torrefaction treatment. The energy required for grinding torrefied pellets is less than 50% of the energy needed for grinding the untreated pellets. In comparison to untreated pellets, the particles from ground torrefied pellets have clearly smaller sizes in a narrower size range. The increase of torrefaction severity improved hydrophobicity of the pellets, which have high resistance to water uptake and maintain their integrity after immersion testing. Upon torrefaction treatment, the durability and tensile strength of the pellets slightly decreased. Scanning electron microscopy analysis results show that particles from wood pellets torrefied at 275 °C lost their fibrous structure with an evident decrease of length/diameter ratios compared to untreated wood pellets. The particles from ground torrefied pellets are more uniform in terms of shape and size. Torrefaction can considerably improve grindability and uniformity of wood-based pellets and make them more acceptable in pulverized fuel applications."

BioCarbUp in Energy & Fuels

One BioCarbUp associated work has been published in Energy & Fuels:

Aekjuthon Phounglamcheik, Liang Wang, Henrik Romar, Norbert Kienzl, Markus Broström, Kerstin Ramser, Øyvind Skreiberg, Kentaro Umeki (2020). Effects of Pyrolysis Conditions and Feedstocks on the Properties and Gasification Reactivity of Charcoal from Woodchips. The abstract is given below.

"Pyrolysis conditions in charcoal production affect yields, properties, and further use of charcoal. Reactivity is a critical property when using charcoal as an alternative to fossil coal and coke, as fuel or reductant, in different industrial processes. This work aimed to obtain a holistic understanding of the effects of pyrolysis conditions on the reactivity of charcoal. Notably, this study focuses on the complex effects that appear when producing charcoal from large biomass particles in comparison with the literature on pulverized biomass. Charcoals were produced from woodchips under a variety of pyrolysis conditions (heating rate, temperature, reaction gas, type of biomass, and bio-oil embedding). Gasification reactivity of produced charcoal was determined through a thermogravimetric analysis at an isothermal condition of 850 °C and 20% of CO_2. The charcoals were characterized for the elemental composition, specific surface area, pore volume and distribution, Raman spectroscopy, and inductively coupled plasma optical emission spectrometry. The analysis results were used to elucidate the relationship between the pyrolysis conditions and the reactivity. Heating rate and temperature were the most influential pyrolysis parameters affecting charcoal reactivity, followed by reaction gas and bio-oil embedding. The effects of these pyrolysis conditions on charcoal reactivity could primarily be explained by the difference in meso- and macropore volume, and the size and structure order of aromatic clusters. The lower reactivity of slow pyrolysis charcoals also coincided with its lower catalytic inorganic content. The reactivity difference between spruce and birch charcoals appears to be mainly caused by the difference in catalytically active inorganic elements. Contrary to pyrolysis of pulverized biomass, low heating rate produced higher specific surface area compared with high heating rate. Furthermore, the porous structure and the reactivity of charcoal produced from woodchips were influenced when the secondary char formation was promoted, which cannot be observed in pyrolysis of pulverized biomass."

BioCarbUp at TMS 2020

One BioCarbUp associated work was presented at TMS 2020 Annual Meeting & Exhibition, 23-27 February 2020, San Diego, California, USA:

Camilla Sommerseth, Ove Darell, Bjarte Øye, Anne Støre, Stein Rørvik (2020). Charcoal and use of Green Binder for use in Carbon Anodes in the Aluminium Industry.

A corresponding article has been published in Light Metals 2020, pp. 1338-1347. The abstract is given below.

"Carbon anodes for aluminium production are produced from calcined petroleum coke (CPC), recycled anode butts and coal tar pitch (CTP). The CO_2 produced during anode consumption contributes to a substantial amount of the CO_2 footprint of this industrial process. Charcoal from wood has been suggested to partly replace coke in anodes but high porosity, low electrical resistivity and high ash content contributes negatively to final anode properties. In this work, charcoal from Siberian larch and spruce was produced by heat treatment to 800, 1200 and 1400 ℃ and acid-washed with H_2SO_4. Acid-washing resulted in reduced metal impurity and the porosity decreased with increasing heat treatment. Pilot anodes were made from CTP, CPC with some additions of spruce and larch charcoal. Another set of pilot anodes were produced using a green binder. Compared to reference anodes, the CO_2 reactivity of anodes containing larch was less affected compared to anodes containing spruce. The green binder was found to be highly detrimental for the anodes' CO_2 reactivity properties. Electrochemical consumption increased for anodes containing both green binder, larch and spruce compared to the reference anode."

BioCarbUp in Journal of Thermal Analysis and Calorimetry

One BioCarbUp work has been published in Journal of Thermal Analysis and Calorimetry:
Gábor Várhegyi, Liang Wang, Øyvind Skreiberg (2019). Non-isothermal kinetics: Best fitting empirical models instead of model-free methods. The abstract is given below.

"The isoconversional (or model-free) methods cannot provide meaningful kinetic description for most samples in thermal analysis. Nevertheless, they can serve as empirical models. A usable empirical model should describe well the observed data and should be suitable for predictions, too. For this purpose, the functions in the isoconversional kinetic equation were parametrized, and the parameters were determined by the method of least squares. This procedure ensures that the data calculated from the model would be close to the experimental data. The present work supplemented a preceding work of Várhegyi (Energy and Fuels 33:2348–2358, 2019) by further considerations and by various evaluations on the TGA curves of a wood sample. The prediction capabilities of the models were also tested. It was found that an evaluation based on three experiments with constant heating rates could predict well two further experiments with stepwise temperature programs. Furthermore, a modification of the model was proposed and examined. The aim of this modification was to improve the fit quality without increasing the number of parameters in the least-squares procedure."

BioCarbUp in Applied Energy

One BioCarbUp associated work has been published in Applied Energy:
Lorenzo Riva, Henrik Kofoed Nielsen, Øyvind Skreiberg, Liang Wang, Pietro Bartocci, Marco Barbanera, Gianni Bidini, Francesco Fantozzi (2019). Analysis of optimal temperature, pressure and binder quantity for the production of biocarbon pellet to be used as a substitute for coke. The abstract is given below.

"In order to contribute to the decarbonization of the economy, efficient alternatives to coal and coke should be found not only in the power sector but also in the industrial sectors (like steel, silicon and manganese production) in which coal and coke are used as a reductant and for steel production also as a fuel. To this aim many research works have been focused on the development of a coke substitute based on woody biomass and known as "biocarbon". There are still barriers to overcome, among them: the biocarbon low density, poor mechanical strength and high reactivity. In this paper a new biocarbon production methodology is proposed, based on: pyrolysis at 600 °C, densification (using pyrolysis oil as binder), reheating of the obtained pellet. Response surface methodology with a Box-Behnken experimental design was utilized to evaluate the effects of the process conditions on the pellet's quality. Responses showed that densification was mainly affected by oil content and pelleting temperature, while pelleting pressure had a minor influence. The pelleting process has been finally optimized using Derringer's desired function methodology. Optimal pelletizing conditions are: temperature equal to 60 °C, pressure equal to 116.7 MPa, oil content concentration of 33.9 wt%. These results are relevant for metal production industries at a global level. The identified optimal parameters of the new biocarbon production process can contribute to replace coke with sustainable fuels and probably reduce great part of the related greenhouse gases emissions."

BioCarbUp at JTACC 2019

One BioCarbUp work was presented at 2nd Journal of Thermal Analysis and Calorimetry Conference (JTACC), 8-21 June 2019, Budapest, Hungary:
Gábor Várhegyi, Liang Wang, Øyvind Skreiberg (2019). Non-isothermal kinetics: best fitting empirical models instead of model-free methods.
A corresponding article has been published in Journal of Thermal Analysis and Calorimetry.

BioCarbUp at ISFR 2019

One BioCarbUp associated work was presented at 10th International Symposium on Feedstock Recycling of Polymeric Materials (ISFR), 26-29 May 2019, Budapest, Hungary:
Bence Babinszki, Viktor Terjék, Luca Kőhalmi, Eszter Barta-Rajnai, Zoltán Sebestyén, Zoltán May, Emma Jakab, Zsuzsanna Czégény (2019). Comparative study of torrefaction oils of rape straw and black locust waste.

BioCarbUp in EERA Bioenergy Newsletter

An article entitled "Optimising the biocarbon value chain for a sustainable metallurgical industry" presented BioCarbUp in an EERA (European Energy Research Alliance) Bioenergy newsletter.

Publication list

Liang Wang, Øyvind Skreiberg, Zsuzsanna Czégény, Maria N.P. Olsen, Karl Oskar Pires Bjørgen (2021). Production and Characterization of Biochar from Woody Biomass under Different Pyrolysis Conditions. EUBCE 2021, 26-29 April, online.

Liang Wang, Øyvind Skreiberg, Zsuzsanna Czégény, Roman Tschentscher, Maria N.P. Olsen, Karl Oskar Pires Bjørgen (2021). Characterization of Liquid By-products from Slow Pyrolysis of Woody Biomass. EUBCE 2021, 26-29 April, online.

Øyvind Skreiberg, Liang Wang, Zsuzsanna Czégény, Scott Turn (2021). Tuning the pyrolysis process in the direction of satisfying quality demands of metallurgical industries. ePyro2021, 12-13 April, online.

Boyao Wang, Tian Li, Terese Løvås, Liang Wang, Øyvind Skreiberg (2021). CFD-DEM modelling of biomass pyrolysis using multi-component kinetics mechanism. ePyro2021, 12-13 April, online.

Zoltán Sebestyén, Bence Babinszki, Janos Bozi, Emma Jakab, Luca Kőhalmi, Liang Wang, Øyvind Skreiberg, Zsuzsanna Czégény (2021). Effect of slow pyrolysis conditions on biocarbon yield and properties: Characterisation of the volatiles. International Conference on Biotechnology for Sustainable Agriculture, Environment and Health, 4-8 April 2021, Jaipur, Rajasthan, India.

Boyao Wang, Jingyuan Zhang, Terese Løvås, Tian Li (2021). CFD-DEM modeling of biomass pyrolysis in a fixed bed reactor. 38th International Symposium on Combustion, 24-29 January 2021, Adelaide, Australia.

Hamideh Kaffash, Gerrit Ralf Surup, Merete Tangstad (2021). Densification of Biocarbon and Its Effect on CO_2 Reactivity. Processes 9, 193.

Øyvind Skreiberg (2021). Biokarbon verdikjeden for metallurgisk industri – Forskningsnytt og -behov. Norsk Biokullnettverk Fagseminar om biokarbon i Norsk prosessindustri, 21 januar 2021, Arendal.

Lorenzo Riva, Liang Wang, Giulia Ravenni, Pietro Bartocci, Therese Videm Buø, Øyvind Skreiberg, Francesco Fantozzi, Henrik Kofoed Nielsen (2021). Considerations on factors affecting biocarbon densification behavior based on a multiparameter model. Energy 221, 119893.

Hamideh Kaffash, Merete Tangstad (2020). Densification and CO_2 reactivity of charcoal. Nasjonal konferanse for materialteknologi, 2-3 December 2020, Trondheim, Norway.

Gábor Várhegyi, Liang Wang, Øyvind Skreiberg (2020). Empirical Kinetic Models for the Combustion of Charcoals and Biomasses in the Kinetic Regime. Energy & Fuels 34(12):16302-16309.

Liang Wang, Lorenzo Riva, Øyvind Skreiberg, Roger Khalil, Pietro Bartocci, Qing Yang, Haiping Yang, Xuebin Wang, Dengyu Chen, Magnus Rudolfsson, Henrik Kofoed Nielsen (2020). Effect of Torrefaction on Properties of Pellets Produced from Woody Biomass. Energy & Fuels 34(12):15343-15354.

Pietro Bartocci, Lorenzo Riva, Henrik Kofoed Nielsen, Qing Yang, Haiping Yang, Øyvind Skreiberg, Liang Wang, Giulio Sorbini, Eid Gul, Marco Barbanera, Francesco Fantozzi (2020). How to produce green coke? 2020 MIT A+B Applied Energy Symposium - e-conference, 13-14 August.

Liang Wang, Lorenzo Riva, Øyvind Skreiberg, Pietro Bartocci, Henrik Kofoed Nielsen, Francesco Fantozzi (2020). Effect of Pyrolysis Conditions and Use of Condensates as Binder on Densification of Biocarbon. 28th European Biomass Conference & Exhibition - e-conference, 6-9 July.

Aekjuthon Phounglamcheik, Liang Wang, Henrik Romar, Norbert Kienzl, Markus Broström, Kerstin Ramser, Øyvind Skreiberg, Kentaro Umeki (2020). Effects of Pyrolysis Conditions and Feedstocks on the Properties and Gasification Reactivity of Charcoal from Woodchips. Energy & Fuels 34(7):8353-8365.

Camilla Sommerseth, Ove Darell, Bjarte Øye, Anne Støre, Stein Rørvik (2020). Charcoal and use of Green Binder for use in Carbon Anodes in the Aluminium Industry. Light Metals 2020, The Minerals, Metals & Materials Series, pp. 1338-1347.

Øyvind Skreiberg (2020). Ulike pyrolyseteknologier og teknikker. Norsk Biokullnettverk Fagseminar Metallindustri, 17 januar 2020, Trondheim.

Øyvind Skreiberg (2020). Oppsummering og oversikt over relevant forskning i Norge og Norden. Norsk Biokullnettverk Fagseminar Metallindustri, 17 januar 2020, Trondheim.

Gøril Jahrsengene, Camilla Sommerseth, Ove Darell, Bjarte Øye, Anne Støre, Stein Rørvik (2020). Charcoal and use of Green Binder for use in Carbon Anodes in the Aluminium Industry. TMS 2020 Annual Meeting & Exhibition, 23-27 February 2020, San Diego, California, USA. A corresponding article has been published in conference proceedings.

Gábor Várhegyi, Liang Wang, Øyvind Skreiberg (2019). Non-isothermal kinetics: Best fitting empirical models instead of model-free methods. Journal of Thermal Analysis and Calorimetry. https://doi.org/10.1007/s10973-019-09162-z

Lorenzo Riva, Henrik Kofoed Nielsen, Øyvind Skreiberg, Liang Wang, Pietro Bartocci, Marco Barbanera, Gianni Bidini, Francesco Fantozzi (2019). Analysis of optimal temperature, pressure and binder quantity for the production of biocarbon pellet to be used as a substitute for coke. Applied Energy 256, 113933.

Øyvind Skreiberg (2019). Optimising the biocarbon value chain for sustainable metallurgical industry. Eramet metallurgical meeting, 4 September 2019, Trondheim.

Øyvind Skreiberg (2019). BioCarbUp – Optimalisering av biokarbon verdikjeden for en bærekraftig metallurgisk industri. SINTEF blogg 12 august 2019.

Gábor Várhegyi, Liang Wang, Øyvind Skreiberg (2019). Non-isothermal kinetics: best fitting empirical models instead of model-free methods. 2nd Journal of Thermal Analysis and Calorimetry Conference (JTACC), 18-21 June 2019, Budapest, Hungary.

Øyvind Skreiberg (2019). Karbonisering - av hva, og hvordan? Norsk Biokullnettverk seminar, 17 juni 2019, Oslo.

Øyvind Skreiberg (2019). Optimising the biocarbon value chain for a sustainable metallurgical industry. EERA Bioenergy News 11, June 2019, pp. 7-8.

Bence Babinszki, Viktor Terjék, Luca Kőhalmi, Eszter Barta-Rajnai, Zoltán Sebestyén, Zoltán May, Emma Jakab, Zsuzsanna Czégény (2019). Comparative study of torrefaction oils of rape straw and black locust waste. 10th International Symposium on Feedstock Recycling of Polymeric Materials (ISFR), 26-29 May 2019, Budapest, Hungary.

Øyvind Skreiberg (2019). Optimising the biocarbon value chain for sustainable metallurgical industry. SFI Metal Production 2019 Spring Meeting, 24-25 April 2019, Trondheim, Norway.

Øyvind Skreiberg, Liang Wang (2019). Biocarbon activities at SINTEF Energy Research. KPN Reduced CO_2 workshop, 1 April 2019, Trondheim, Norway.