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

Newsletter 1-2022

Progress in 2022

In 2022 the studies connected to the resource base in Norway for biocarbon production will be finalised, results from carbonization experiments in different experimental setups will be published, and increasing efforts are directed towards characterization and upgrading of the biocarbons and by-products. CO_2 and SiO reactivity of biocarbons are in focus, and the focus on the utilization of the bio-oil from biocarbon production as binder in anode baking continues. A new BioCarbUp PostDoc candidate continues the work focusing on modelling related to the biocarbon production process. This last year of the project there will also be increased focus on the overall value chain, including logistics, as well as results dissemination. In general, the scientific activities are progressing well even though the Covid-19 situation did inflict on the progress of experimental activities.

BioCarbUp workshop and steering committee meeting

The fifth BioCarbUp workshop and steering committee meeting was arranged 23-24 March 2022 in Trondheim and was the first physical/hybrid meeting in a long time due to covid-19. 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 candidate working within composite agglomerates with biocarbon has finished her study. The PostDoc candidate, Hamideh Kaffash from Iran, has carried out her work at Department of Materials Science and Engineering, NTNU, with Professor Merete Tangstad as her supervisor. The following publications have resulted from her work:

1) CO_2 Gasification of Densified Biomass: The Influence of K on Reaction Rate
2) The effect of densification on compressive strength of charcoal
3) Densification of Biocarbon and Its Effect on CO_2 Reactivity

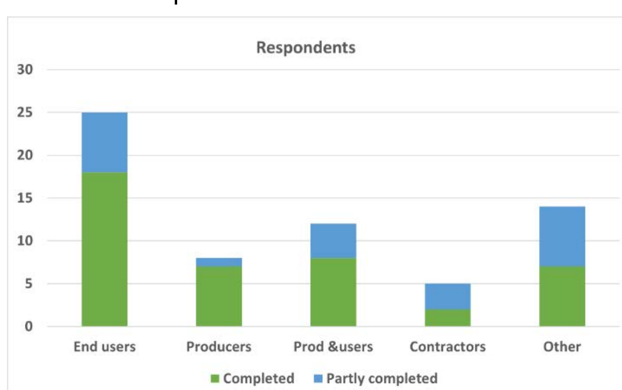
PhD/PostDoc work

The BioCarbUp PhD study within Modelling and CFD simulation of pyrolysis reactors has been changed to a PostDoc study since the candidate, Boyao Wang from China, left his position at Department of Energy and Process Engineering, NTNU, for an industrial work position in Norway. A PostDoc candidate, Jingyuan Zhang, will continue the work, with Professor Terese Løvås as supervisor and Adjunct Associate Professor Tian Li as co-supervisor. Jingyuan has a very relevant background and carried out his PhD work within the GrateCFD knowledge building project. The PostDoc candidate will continue the focus on numerical modelling and simulation for efficient biocarbon production.

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

Future forest bioenergy expectations

In January NIBIO together with the Energy Farm sent a survey to 112 companies.
The purpose of the survey was to feedback on:
• Annual turnover of wood for bioenergy today and expected turnover in the years to come
• Expectations for the energy timber market in the future
• Which quality parameters or wood properties that are considered important or difficult to fulfil



Distribution of respondents in the survey

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

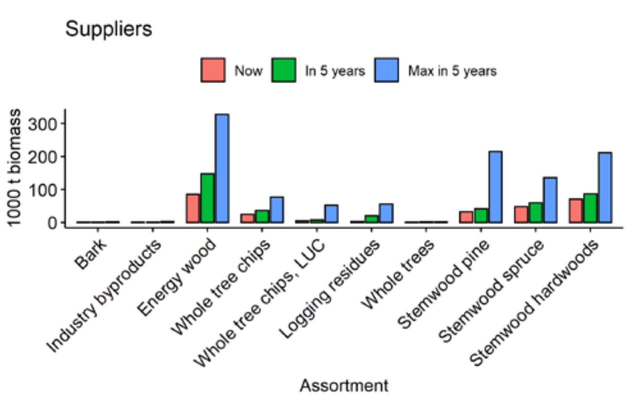
In the survey 42 respondents answered all questions and 22 answered some of the questions. The 112 companies are the contact points we could find regarding larger timber suppliers, bioenergy companies, other players with industrial use of energy wood and energy consultants. The respondents were asked to indicate whether they were to be regarded as a buyer or supplier of energy wood, possibly both, or contractors.

According to the Forest Act and associated regulations, all forest timber that is felled for processing, sale or export must be measured, valued and reported to the Norwegian Directorate of Agriculture's timber database (VSOP). Energy timber assortments sold from forest owners to ordinary timber buyers, i.e. players who also sell other forest timber, are registered in this system.

However, significant amounts of energy wood are not registered anywhere. Solid wood and felling waste from road edge clearing, field edge clearing and land use change (LUC) are often given away, and then in many cases no information is sent to the timber database. When pure bioenergy players buy energy timber from forest owners, it is also not certain that they have established systems that report the measurement note and turnover to the timber database.

The annual turnover of energy wood assortments registered in VSOP currently amounts to approximately 450 - 500,000 m^3, corresponding to an energy amount of 1 TWh.

Those who have given themselves the name supplier have an annual turnover of 170 thousand ton of woody biomass, corresponding to 850 GWh. Suppliers predict a moderate increase over the next five years of energy timber, grot and stemwood. But if the market takes off completely, they see opportunities to triple the deliveries of woody biomass. It is reasonable that this may mean that volumes that are currently exported as pulpwood will be redirected to domestic use as wood for other industrial purposes.

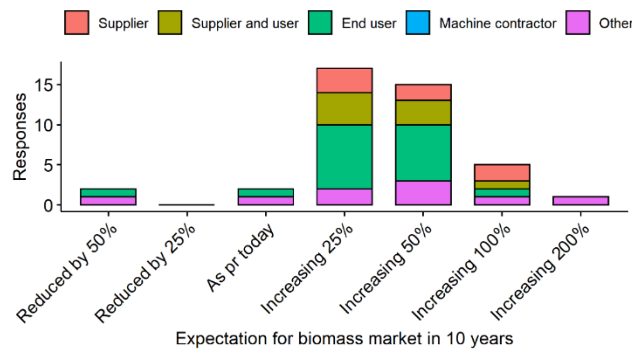


Supplied forest wood distribution today, and average and max expectations from the suppliers in 5 years

Buyers seem to increase the consumption of all sorts of wood. The total annual volume for buyers is 392 thousand ton of wood as of today, and the estimated need is 656 thousand ton of wood in 5 years. This is an increase of 70%.

In order to map which fuel properties that are considered to be the most important, the respondents were asked two questions about this. Almost all (70 - 100%) considered moisture an important property, and this was also the property that most often presented challenges. For fuel buyers, basic density, fine fraction and fraction distribution were also considered important properties. For suppliers and contractors, basic density was considered an important property.

Most timber suppliers believe that the market for energy timber will increase in the order of 50 - 100%, while buyers believe in a somewhat more moderate increase in the range of 25 - 50%. Suppliers expect a moderate increase (10 - 30%) over the next 5 years.



Number and type of respondents expecting from 50% reduction to 200% increase in the demand for forest wood for bioenergy in 10 years

End users are most concerned about the supply of resources, while suppliers are most concerned about the competitiveness of the end product. This may indicate that there is room for a fairly significant increase in deliveries to this market, if the value of the end products is at a sufficient level.

SP2 (Biocarbon production and upgrading) work

Completion of study on effect of calcination on properties of steam exploded pellets

Biocarbon is a promising alternative to reduce utilization of fossil-based coke, and there is a need to identify, test and develop new packing material for use in the anode baking furnace. Pellets produced from steam exploded biomass can be an alternative to fossil coke as a potential covering material in carbon anode production. In early 2022, the study on effect of calcination on properties of steam exploded pellets was completed. The steam exploded pellets were calcinated in a high temperature furnace with presence of N_2 at temperatures relevant to the industrial anode baking process (i.e., 1000, 1100 and 1300 ºC). The critical properties of raw and calcinated steam exploded pellets as covering material were comprehensively characterized and assessed, including weight loss, volatile matter content, mechanical durability and strength. The mechanical durability and compression strength of raw and calcinated steam exploded pellets were tested by using a tumbler tester (Figure 1a) and a hardness tester (Figure 1b) in the SINTEF Energy Research lab in Trondheim. Figure 1c-e show a raw steam exploded pellet and residues after compression strength and durability test. Upon calcination, the mechanical durability and strength of steam exploded pellets decreased as shown in Figure 2, indicating higher potential to generate dust and fines upon calcination treatment. Additionally, the microstructure and ash chemistry of the pellets calcined at different conditions were investigated by using a scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDX). As shown in Figure 3a, SEM analysis revealed that untreated pellets have dense and compact structure with rather smooth and intact surface. Calcination caused formation of cracks and openings on the surface of treated pellets, partially explaining the decrease of mechanical strength of the pellets (Figure 3b-d). In addition, visible agglomeration of ash on calcined pellets surfaces was observed (Figure 3d). Figure 4 shows that calcium is a dominant element in the ash layer on the pellet surface, with presence of K and Mn in minor amounts.

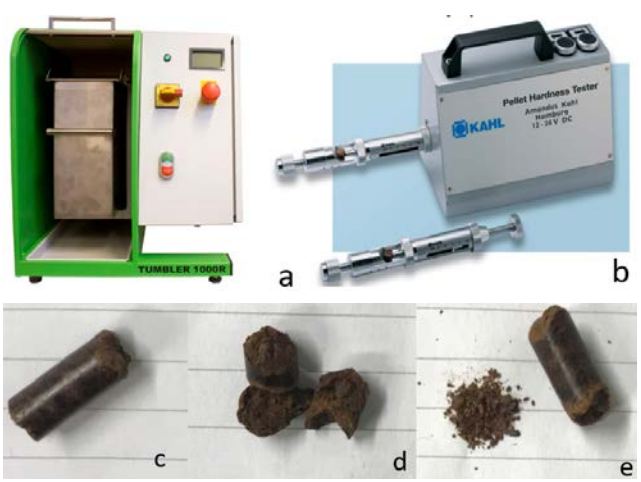


Figure 1. (a) Tumbler pellets durability tester, (b) pellet hardness tester for measuring compression strength, (c) raw steam exploded pellet, (d) broken raw steam exploded pellet after compression strength test, and (e) residues (bulk grain and fines) from raw steam exploded pellet durability test

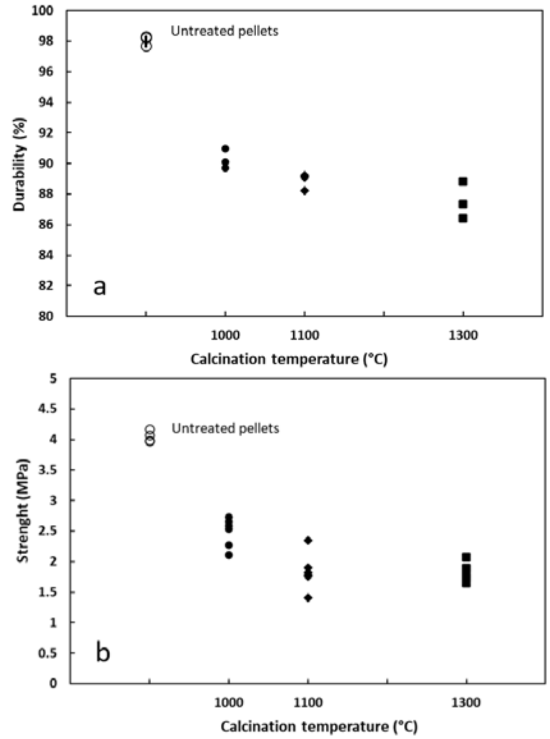


Figure 2. Mechanical durability and strength of raw and calcined steam exploded pellets

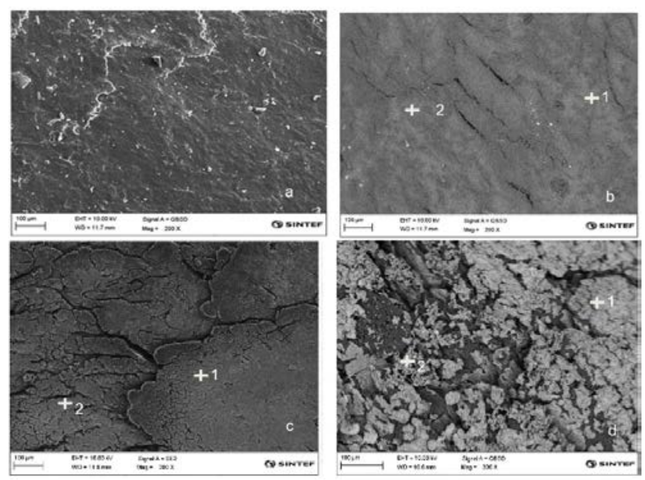


Figure 3. Surface morphology of untreated pellets (a) and pellets calcined at (b)1000, (c)1100 and (d)1300 °C

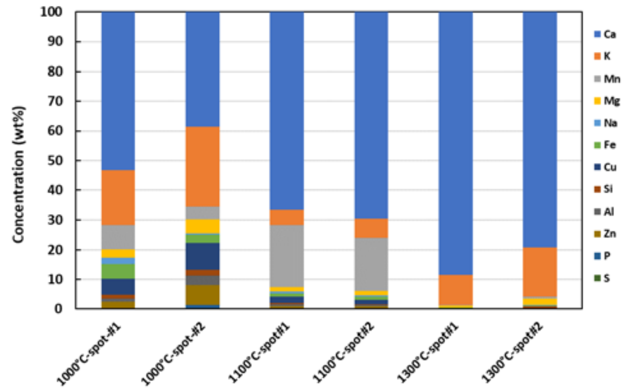


Figure 4: EDX spot analysis on steam exploded pellets calcined at 1000, 1100 and 1300 °C

Fruitful cooperation on biocarbon production and characterization of by-products

To optimize the biocarbon value chain for metallurgical industry, it is important to produce biocarbon with optimized yields and qualities and upgrade the by-products to higher value products. In BioCarbUp, fruitful cooperation on biocarbon production and characterization of by-products has resulted in comprehensive results. Biocarbons have been produced in a lab scale fixed bed reactor at SINTEF Energy Research and a bench scale tubular reactor at the Institute of Materials and Environmental Chemistry, Research Centre for Natural Sciences (RNCS), Budapest. Woodchips, pellets and ground powder from them were fed to the reactor, with biocarbon chips and powder produced (Figure 5a and b). For both reactors, the condensates (Figure 5c) were also collected for detailed chemical composition analyses using GC/MS in RNCS and GCxGC-MS/FID in SINTEF Industry in Oslo. Figure 6a shows a GC/MS spectrum of condensates produced from carbonization of birch wood at 700°C using the lab scale fixed bed reactor and the bench scale tubular reactor. Figure 6b displays the result of GCxGC-MS/FID analysis on condensate from carbonization at 500°C. The GCxGC-MS/FID analysis provided more details about the chemical composition of the condensate and a Van-Krevelen diagram based on their molecular formula. The yields of biocarbon obtained in the two reactors were compared (Figure 7a), and they are quite comparable. The biocarbon yields were considerably enhanced as carbonization of birch and spruce wood was carried out under constrained conditions. For the experiments conducted using the lab scale fixed bed reactor, gas products were monitored and quantified continuously by a micro-GC for establishing the mass balance. Figure 7b displays release of CO from carbonization of birch wood under different conditions. It shows that release behaviours of CO were considerably affected upon purging with a carrier gas (N_2) and when covering the sample bed with a lid, both regarding start of release and the intensity along the spectrum of temperatures. Figure 8a shows an overview of normalized yields of products from carbonization of birch and spruce wood under different conditions. Figure 8b shows the distribution of energy contained in the products from the same experiments. The liquid product, as a main product from wood carbonization, has as can be seen a significant high energy content.

Figure 5: Biocarbon chips and powders and condensate collected from carbonization experiments

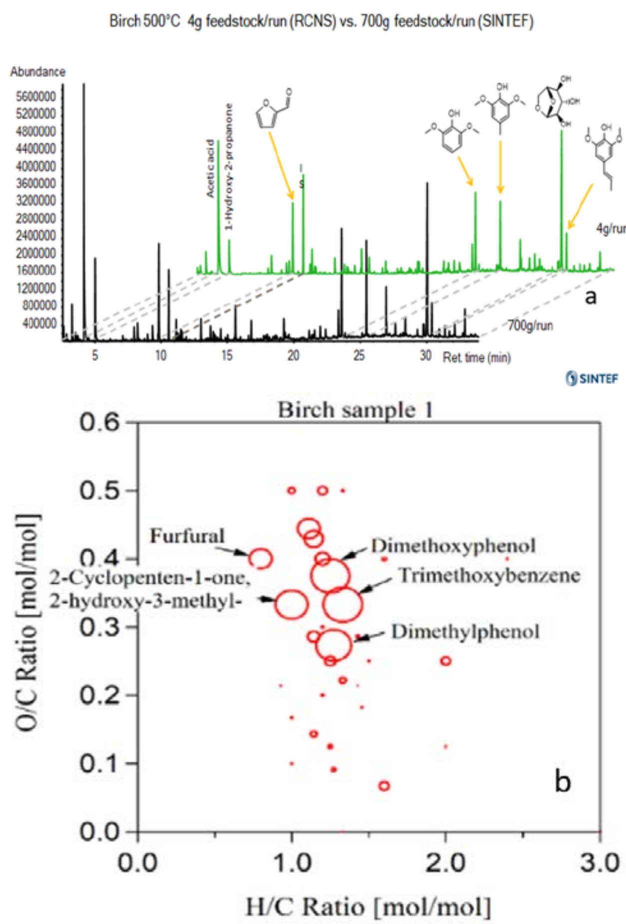


Figure 6: (a) GC/MS spectrums of condensates collected from carbonization of birch wood in lab scale fixed bed reactor and bench scale tubular reactor, (b) Van-Krevelen diagram of chemical composition of the condensate produced from carbonization of birch wood at 500 °C by using a GCxGC-MS/FID

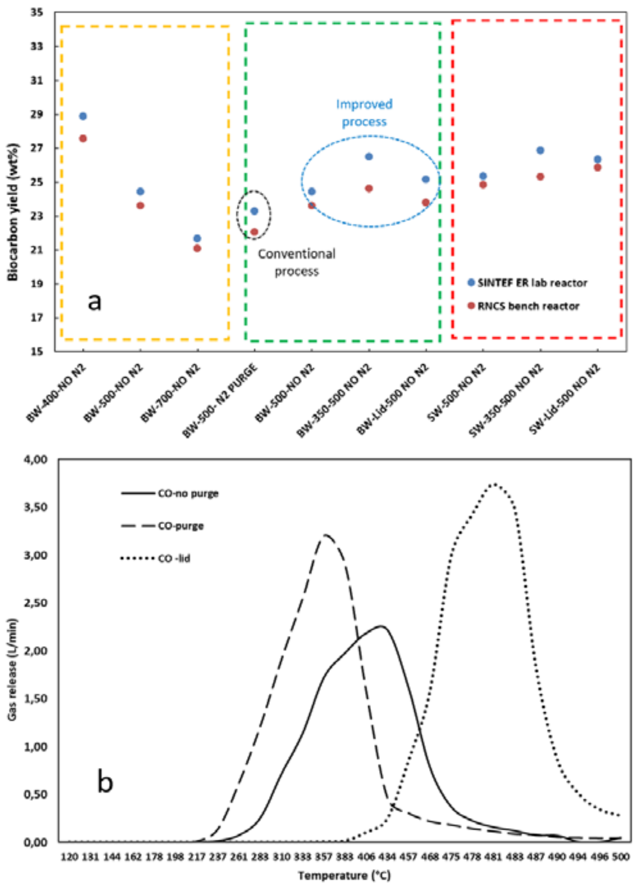


Figure 7: (a) Comparison of biocarbon yields obtained from the lab scale fixed bed reactor and bench scale tubular reactor, (b) release behaviour of CO from carbonization of birch wood using the lab scale fixed bed reactor

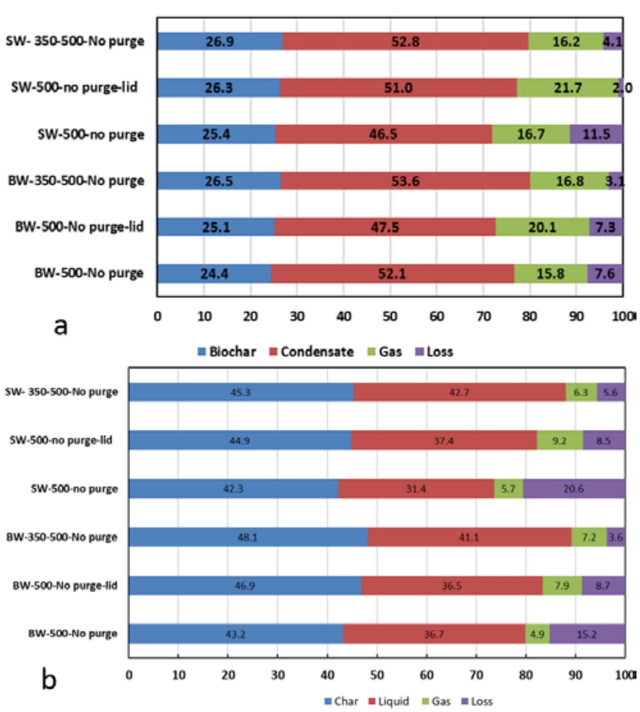


Figure 8: (a) weight and (b) energy distribution of products obtained from carbonization of birch and spruce wood chips under different conditions

Transient plastic phase formation studies

Slow pyrolysis of woody materials under elevated pressure was previously shown to result in macroscopic morphology changes, appearing as though the material experienced a molten phase and was described as transient plastic phase (TPP) biocarbon. Experiments have been conducted to study the influence of pressure, temperature, reactor volume, feedstock, particle size and moisture content on its formation. The results suggest it is mediated through hydrolysis reactions that reduce the molecular weight of the biomass polymers allowing for the charred material to become molten. Elevated pressure plays a key role in keeping water and the low molecular weight volatile compounds in the condensed phase and therefore available to participate in reactions with the solid phase. Despite drastic changes in material morphology (Figure 9), minimal differences between TPP and non-TPP biocarbon properties were detected using proximate analysis, solid state 13C NMR, helium pycnometry, bomb calorimetry. Clear differences between the mechanical properties of pellets formed from the TPP and non-TPP biocarbon products were shown using experiments comparing the compressibility, fracture strength, apparent density, elasticity, and thermal expansion. Work continues to identify sets of reactor conditions that result in TPP biocarbon formation and to control properties.

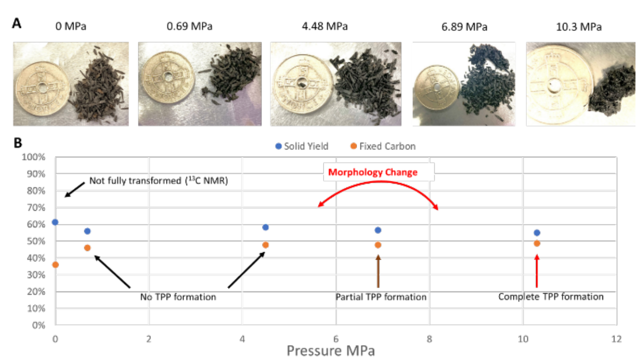


Figure 9: (A) Photographic results from 1-2 mm birch particles following constant pressure carbonization experiments at 320 °C for 30 mins, and (B) Solid yield and fixed carbon content as a function of pressure

SP3 (Biocarbon end-use) work

TMS 2022

The annual TMS meeting was finally back as a physical conference, held February 27th - March 3rd in Anaheim, California. Although some trips were

cancelled due to participants getting Covid, the Norwegian delegation was large. Interesting symposia where the SINTEF and NTNU representatives spent their time included "Decarbonizing the Materials Industry", "Decarbonizing the Aluminum Industry", "Aluminum Reduction Technology" and "Electrode Technology for Aluminum Production".
From BioCarbUp, the paper "Bio-Binders and its Carbonization and Interaction with Petroleum Coke during Baking" was presented by Gøril Jahrsengene on behalf of herself and the co-authors Stein Rørvik, Anne Støre, Liang Wang and Øyvind Skreiberg. The session and presentation were popular and good conversations continued in the break amongst the attendees. The author has also been asked to send the paper to other interested non-attendees post-conference.

4 weeks in Canada!

After planning to go to Canada as part of the BioCarbUp project back in 2020 through the INTPART CaNAl collaboration project, Gøril finally managed a visit to Université Laval in Quebec City after the TMS conference. For four weeks she had an office at campus and was able to join the new PhDs and a PD in the lab. Some great initial work was done on upgrading bio-oils to bio-pitches during this time, which will hopefully result in publications and further collaboration in the future.

Gøril and the team at Laval!

Bio-oil prepared for upgrading

SI-conference 2022

The 16th SI-conference was held digitally 14-16 June, and Sethu presented her paper "Effect of varying SiO contents on Si and FeSi production" on behalf of herself and her co-author Eli Ringdalen. Here it was presented the updated SINTEF SiO reactivity test and a discussion on the reliability of the improved set-up. Furthermore, the effect of partial pressure of SiO on SiC conversion of carbon during the Si/FeSi process was investigated and discussed. Lastly, the correlation between SiC surface crystal formation and CO_2 reactivity of selected carbon materials was investigated. The work presented in the conference has been done in the projects BioCarbUp and Reduced CO_2.

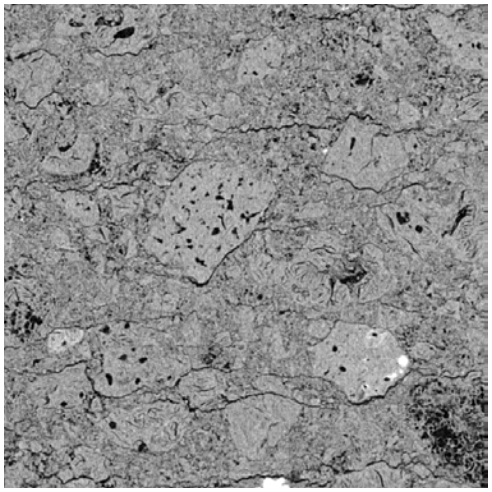
CaNAl Summer School in Trondheim

The third summer school in the INTPART CaNAl collaborative project was held in a hybrid format from Trondheim 14-16 June, with participants from SINTEF, NTNU, Hydro, Alcoa and Elkem, and from academia within aluminium production from the Quebec region in Canada (Universities Laval and Chicoutimi). Within the subject of biocarbon, Professor Duygu Kocaefe held a lecture on modification of anode raw materials during the courses, while Gøril Jahrsengene and Stein Rørvik presented some preliminary results from investigating pilot anodes using both CTP and new bio-pitch materials using µCT in the research presentations.

CaNAl

New X-ray Micro X-ray Equipment

Stein Rørvik has been part of getting the new state-of-the-art industrial X-ray micro-CT scanner up and running, and the Pore Image Laboratory was officially opened May 3rd! The µCT technique has been used in many tasks of the BioCarbUp project, and the acquisition of good results can now happen significantly faster than previously! Contact Stein if you have any needs of CT scans. The new µCT has already been used to obtain scans of pilot anodes for aluminium production, including some made using bio-pitches!



Crop out of vertical view of baked pilot anode made of bio-pitch.

Conferences to come

Eli Ringdalen has been invited to speak at the 61st Annual Conference of Metallurgists (COM) in Montreal, Quebec, August 21-24. We wish her good luck with her talk: "Decarbonization in Ferroalloys and Si-Production - Opportunities and Challenges".

Based on the work done on characterizing pilot anodes for aluminium industry, Stein Rørvik and Gøril Jahrsengene has submitted an abstract to the 40th ICSOBA conference, to be held in Athens, Greece, 10-14 October. The abstract was accepted, and work is currently being done to finish the paper "Characterizing Pilot Anodes made from CTP and Bio-Pitch using µCT" together with our Canadian collaborators. The presentations will all be held in person, but attendees not presenting may also attend the conference online.

Stein Rørvik is also preparing an abstract and paper on use of µCT on biocarbons used in the CO_2 reactivity test and SiO reactivity tests for TMS 2023, and Nicholas Smith-Hanssen will be in charge of the contribution on the testing and characterization methods for carbon materials for the metallurgical industries for the same conference. Both will submit to the symposia "Advances in Pyrometallurgy: Developing Low Carbon Pathways ". The conference will be held in San Diego, California 19-23 March 2023. Abstracts for TMS are accepted until July 1st!

BioCarbUp at Silicon for the chemical and solar industry XVI

One BioCarbUp work has been presented at Silicon for the chemical and solar industry XVI, 14-16 June, Trondheim, Norway:

Sethulakshmy Jayakumari, Eli Ringdalen (2022). Effect of varying SiO contents on Si and FeSi production.

A corresponding article has been published in proceedings. The abstract is given below:

"During primary silicon (Si) production in submerged arc furnaces, silicon carbide (SiC) is one of the main intermediate compounds generated due to the interaction of carbon materials and silicon monoxide (SiO (g)). A complete conversion of SiC from carbon materials is significant and has great importance on the Si yield. The SiO reactivity of carbon materials, their ability to form SiC is thus important for Si-production. The SiO reactivity depends on the properties of carbon materials such as porosity, surface area and cell wall thickness. Their effect on SiO-reactivity has here been studied for charcoal, coal and char and compared with CO_2 reactivity for the materials. The reactivity of carbon materials has been measured by the SINTEF SiO reactivity test, that takes place at low partial pressure of SiO (pSiO < 0.01 bar) and at 1650 °C. The test has been updated and the reliability of the improved set up are discussed. In the industrial Si process, the process gas, which is a mixture of SiO and CO, with higher partial pressures of SiO than 0.01 bar can be in contact with unreacted carbon. The effect of partial pressure of SiO on SiC conversion of carbon have been investigated and is discussed. In addition, the correlation between SiC surface crystal formation and CO_2 reactivity of the selected carbon materials have also been investigated."

BioCarbUp at IConBM2022

Two BioCarbUp works have been presented at IConBM2022, 5-8 June, Naples, Italy:

1) Liang Wang, Øyvind Skreiberg, Nicholas Smith-Hanssen, Sethulakshmy Jayakumari, Gøril Jahrsengene, Stein Rørvik, Scott Turn (2022). Investigation of the properties and reactivity of biocarbons at high temperature in mixture of CO/CO_2.

2) Liang Wang, Lukas Baldauf, Øyvind Skreiberg, Gøril Jahrsengene, Stein Rørvik (2022). Effect of calcination temperature and time on properties of steam exploded pellets.

Corresponding articles have been accepted for publication in proceedings.

Liang Wang giving one of his two presentations

BioCarbUp at Pyro2022

Two BioCarbUp works have been presented at Pyro2022, 15-20 May, Ghent, Belgium:

1) Liang Wang, Øyvind Skreiberg, Nicholas A. Smith, Sethulakshmy Jayakumari, Stein Rørvik, Gøril Jahrsengene, Yang Zhang, Aekjuthon Phounglamcheik, Kentaro Umeki, Scott Turn (2022). Investigation of the properties and reactivity of biocarbon at high temperature in mixture of CO/CO_2.

2) Liang Wang, Øyvind Skreiberg, Karl Oskar Pires Bjørgen, Maria N.P. Olsen, Zsuzsanna Czégény, Morten Grønli (2022). A comparative study on the effect of slow pyrolysis temperature on softwood and hardwood pyrolysis products yields and biochar properties.

BioCarbUp at TMS 2022

One BioCarbUp work has been presented at TMS 2022 Annual Meeting & Exhibition, 27 February - 3 March 2022, Anaheim, California, USA:

Gøril Jahrsengene, Stein Rørvik, Anne Støre, Liang Wang, Øyvind Skreiberg (2022). Bio-Binders and its Carbonization and Interaction with Petroleum Coke during Baking.

A corresponding article has been published in proceedings.

BioCarbUp in JOM

One BioCarbUp work has been published in The Journal of The Minerals, Metals & Materials Society:

Hamideh Kaffash, Merete Tangstad (2022). [CO_2 Gasification of Densified Biomass: The Influence of K on Reaction Rate]. The abstract is given below:

"The Boudouard reactivity of metallurgical coke and densified charcoals was investigated in this study. Potassium is known to accumulate in ferromanganese furnaces and hence was evaluated as a catalyst of CO_2 reactivity. Samples were impregnated using a gaseous impregnation technique with K_2CO_3.The reactivity experiments were designed to simulate conditions occurring in an industrial furnace, as used for production of Mn-alloys. To find out the catalytic effect of potassium, the concentration varied from a fraction of a percent up to 5 wt.%. The results show that with increasing potassium content, the CO_2 reactivity of coke and charcoal increased, and this change was more significant for coke. The CO_2 reactivities of coke and densified charcoal were much closer to each other at the highest content of potassium. Scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS) showed that potassium distributed on the surface as well as on deposited carbon particles formed on densified charcoal."

BioCarbUp in Light Metals

One BioCarbUp work has been published in Light Metals 2022: Electrode Technology for Aluminum Production:

Gøril Jahrsengene, Stein Rørvik, Anne Støre, Liang Wang, Øyvind Skreiberg (2022). [Bio-Binders and its Carbonization and Interaction with Petroleum Coke during Baking]. The abstract is given below:

"To reduce the carbon footprint in aluminium production, bio-based binders are suggested to replace some or all coal tar pitch in the carbon anodes. In this study, bio-binders based on Norwegian spruce and birch woods were produced in a laboratory set-up, which were studied in terms of wetting properties towards petroleum coke. The binders were mixed with petroleum coke and baked to three different temperatures. Graphitization of the binders were investigated on pure carbonized binders by XRD. Optical light microscopy was used to investigate the structures and interactions between coke and binder after baking. The bio-based binders appeared to adhere well to the coke particles, indicating excellent wetting behaviour during mixing. The optical structure of the carbonized bio-binder seemed to be affected by strain due to shrinkage of the bio-binder around the coke grain boundaries."

BioCarbUp in JAAP

One BioCarbUp connected work has been published in Journal of Analytical and Applied Pyrolysis:

Yanqi Xie, Hailong Li, Lena Johansson Westholm, Lara Carvalho, Liang Wang, Eva Thorin, Zhixin Yu, Xinhai Yu, Øyvind Skreiberg (2022). [A critical review on production, modification and utilization of biochar]. The abstract is given below:

"There has been an increased interest in the production of sustainable biochar in the past years, as biochar show versatile physicochemical properties and therefore can have a wide applicability in diverse fields. Comprehensive studies have been made to characterize biochar produced from various biomass materials, using different production technologies and under different process conditions. However, research is still lacking in correlating biochar properties needed for certain applications with (i) selection of feedstock, (ii) biochar production process and conditions and (iii) biochar upgrading and modification strategies. To produce biochar with the desired properties, there is a need to establish and clarify such correlations, which can be used for further proper selection of feedstock, tuning and optimization of the production process and more efficient utilization of biochar. On the other hand, further elucidation of these correlations is also important for biochar-stakeholder and end-users for predicting physiochemical properties of biochar from certain feedstock and production conditions, assessing potential effects of biochar utilization and clearly address needs towards biochar critical properties. This review summarizes a wide range of literature published on the impact of feedstocks and production processes and reactions conditions on the biochar properties. In addition, this review reports and discusses the most important biochar properties required for the different potential applications. Based on this review, knowledge gaps and perspectives for future research have been identified regarding the characterization and production of biochar. This review has also highlighted the importance of assessing performance of biochar for certain applications."

Other news

Two new knowledge building projects on biocarbon for metallurgical industry

The Research Council of Norway announced in June that two new knowledge building projects on biocarbon for metallurgical industry have been granted funding:

1) Upgrading biocarbon for sustainable metallurgical industries, led by SINTEF Energy Research
2) Biocarbon in metal production - Transfer of research to industrial use, led by SINTEF Industry

These two projects will timely continue the knowledge building within the topic biocarbon for metallurgical industry, succeeding BioCarbUp and Reduced CO_2, that are both ending by the end of this year.

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 good progress.

Eramet Norway has received financial support from Enova for introducing biocarbon into their metallurgical process in Norway

Enova has granted 62.1 MNOK to Eramet Norway to support introduction of adapted biocarbon targeted at satisfying quality requirements of their Mn-alloy metallurgical process, to replace metallurgical coke currently used as reductant. To meet the qualities of the adapted biocarbon, also possibilities for changes in the metallurgical process itself will be investigated. See press release from Enova here.

Vow ASA has received financial support from Enova for establishing biocarbon production at Follum in Norway

Enova has granted 80.7 MNOK to VoW ASA to support erection of a biocarbon pilot production plant at Follum in Norway. The aim is to produce a biocarbon quality suitable for the metallurgical industry See press release from Enova here.

Elkem signs new agreement for Norwegian biocarbon

Elkem has signed a Letter of Intent (LoI) with Vow ASA's wholly owned subsidiary Vow Industries with the aim of reducing fossil CO_2-emissions from the production of silicon and ferrosilicon products for the global market. See the press release here.

Oplandske Bioenergi with the first commercial biochar production plant in Norway

The Oplandske Bioenergi biochar production plant at Rudshøgda in Norway produces EBC certified biochar and is the first biochar producer in Norway in commercial operation.

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. The Prosess21 main report, summarises the Prosess21 work.
For more info about Prosess21:
https://www.prosess21.no/

PhD thesis on Bio-coal for the Sustainable Industry

Aekjuthon Phounglamcheik, a PhD student at Luleå University in Sweden, defended his PhD thesis 24 September 2021. He was in his work also collaborating with BioCarbUp. The thesis is available here.

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 2020. 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 more than 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. The most recent dissemination effort was a parallel session on biochar during Bioenergidagene 2021, where Øyvind Skreiberg gave a presentation on the topic of the biocarbon value chain for metallurgical industry. 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. See also their recent activity report 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. IBI news are available here.

European Biochar Industry Consortium (EBI)

EBI is supporting the development of biochar applications and is a network og many industrial actors connected to biocarbon production and utilisation. Earlier Norsk Biokullnettverk had an active link to the International Biochar Initiative, but this has changed to EBI, i.e. with an increased industrial and European focus.

Recent events

ICSOBA 2021, 22-24 November. e-conference
https://icsoba.org/past-events-icsoba/

Pacifichem 2021, 16-21 December. e-conference
https://pacifichem.org/

TMS 2022 Annual Meeting & Exhibition, 27 February – 3 March 2022, California.
https://www.tms.org/AnnualMeeting/TMS2022

30th European Biomass Conference & Exhibition, 9-12 May 2022, Marseille, France. + e-conference
http://www.eubce.com/

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

IConBM 2022, 5-8 June, Naples, Italy.
https://www.aidic.it/iconbm2022/

Silicon for the Chemical and Solar Industry XVI, 14-16 June 2022, Trondheim, Norway.
https://www.ntnu.edu/si-conference

Upcoming events

39th International Symposium on Combustion, 24-29 July 2022, Vancouver, Canada.
http://www.combustionsymposia.org/2022/

ICSOBA 2022, 10-14 October 2022, Athens, Greece and online.
https://icsoba.org/2022/

1st International Conference on Energy, Environment & Digital Transition, 23-26 October 2022, Milano, Italy. https://www.aidic.it/e2dt/

TMS 2023 Annual Meeting & Exhibition, 19-23 March 2023, San Diego, California, USA.
https://www.tms.org/AnnualMeeting/TMS2023

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:

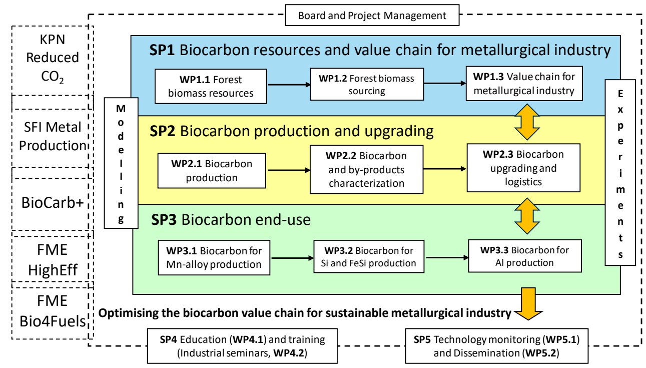
- **Production of biocarbon with sufficient quality** satisfying the end user quality requirements while ensuring optimum utilisation of the by-products
- **Optimised sourcing of Norwegian forest resources** for biocarbon production towards the specific metallurgical processes
- **Maximising the energy 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 **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 has been 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, who has shown that biocarbon can effectively be upgraded by deposition of carbon from methane on the surfaces of the porous biocarbon. She has now finished her study. 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.

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 Pacifichem

One BioCarbUp work has been presented at The International Chemical Congress of Pacific Basin Societies 2021, 16-21 December 2021, online:
Robert Johnson, Christian Castillo, Kyle Castillo, Scott Turn, Liang Wang, Øyvind Skreiberg (2021). Constant volume carbonization of biomass: results from an experimental investigation.

BioCarbUp in ACS Omega

One BioCarbUp connected work has been published in ACS Omega:
Aekjuthon Phounglamcheik, Ricardo Vila, Norbert Kienzl, Liang Wang, Ali Hedayati, Markus Broström, Kerstin Ramser, Klas Engvall, Øyvind Skreiberg, Ryan Robinson, Kentaro Umeki (2021). CO_2 gasification reactivity of char from high-ash biomass. The abstract is given below:

"Biomass char produced from pyrolysis processes is of great interest to be utilized as renewable solid fuels or materials. Forest byproducts and agricultural wastes are low-cost and sustainable biomass feedstocks. These biomasses generally contain high amounts of ash-forming elements, generally leading to high char reactivity. This study elaborates in detail how chemical and physical properties affect CO_2 gasification rates of high-ash biomass char, and it also targets the interactions between these properties. Char produced from pine bark, forest residue, and corncobs (particle size 4−30 mm) were included, and all contained different relative compositions of ash-forming elements. Acid leaching was applied to further investigate the influence of inorganic elements in these biomasses. The char properties relevant to the gasification rate were analyzed, that is, elemental composition, specific surface area, and carbon structure. Gasification rates were measured at an isothermal condition of 800 °C with 20% (vol.) of CO_2 in N_2. The results showed that the inorganic content, particularly K, had a stronger effect on gasification reactivity than specific surface area and aromatic cluster size of the char. At the gasification condition utilized in this study, K could volatilize and mobilize through the char surface, resulting in high gasification reactivity. Meanwhile, the mobilization of Ca did not occur at the low temperature applied, thus resulting in its low catalytic effect. This implies that the dispersion of these inorganic elements through char particles is an important reason behind their catalytic activity. Upon leaching by diluted acetic acid, the K content of these biomasses substantially decreased, while most of the Ca remained in the biomasses. With a low K content in leached biomass char, char reactivity was determined by the active carbon surface area."

BioCarbUp at CUUTE-1

One BioCarbUp work has been presented at The First Symposium on Carbon Ultimate Utilization Technologies for the Global Environment (CUUTE-1), 14-17 December 2021, Nara, Japan & online:
Hamideh Kaffash, Merete Tangstad (2021). The effect of densification on charcoal properties.

BioCarbUp at ICAE 2021

One BioCarbUp work has been presented at International Conference on Applied Energy, 29 Nov - 5 Dec, online:
Liang Wang, Lorenzo Riva, Øyvind Skreiberg, Zsuzsanna Czégény, Pietro Bartocci, Henrik Kofoed Nielsen (2021). Study on Densification of Biocarbon for Metal Production Application.
A corresponding article has been accepted for publication in proceedings.

BioCarbUp at ISFR 2021

One BioCarbUp work has been presented at International Symposium on Feedstock Recycling of Polymeric Materials, 29-30 November 2021, online:
Zsuzsanna Czégény, Bence Babinszki, Zoltán Sebestyén, Emma Jakab, Luca Kőhalmi, Janos Bozi, Liang Wang, Øyvind Skreiberg (2021). Effect of carbonization conditions on the yield and properties of biocarbon and bio-oil products.

BioCarbUp at ICSOBA 2021

One BioCarbUp work has been presented at 39th Conference of The International Committee for Study of Bauxite, Alumina & Aluminium, 22-24 November 2021, online:
Gøril Jahrsengene, Stein Rørvik, Anne Støre, Liang Wang, Øyvind Skreiberg (2021). Production of Bio-binders from Pyrolysis Condensates and its Interaction with Calcined Petroleum Coke.
A corresponding article has been published in proceedings.

BioCarbUp in ACS Omega

One BioCarbUp work has been published in ACS Omega:
Gábor Várhegyi, Liang Wang, Øyvind Skreiberg (2021). [Empirical Kinetic Models for the CO_2 Gasification of Biomass Chars. Part 1. Gasification of Wood Chars and Forest Residue Chars]. The abstract is given below:

"The gasification kinetics of charcoals and biomass chars is complicated by several factors, including chemical and physical inhomogeneities, the presence of mineral matter, and the irregular geometry of the pore structure. Even the theoretically deduced gasification models can only provide empirical or semiempirical descriptions. In this study, an empirical kinetic model from the earlier works of the authors was adapted for the CO_2 gasification of biomass chars. It is based on a versatile polynomial approximation that helps to describe the dependence of the reaction rate on the progress of the conversion. The applicability of the model was tested by the reevaluation of 24 thermogravimetric analysis (TGA) experiments from earlier publications. The adjustable parameters of the model were determined by the method of least squares by evaluating groups of experiments together. Two evaluation strategies were tested. In the regular evaluations, the same kinetic parameters were employed for all the experiments with a given sample. The use of experiments with modulated and constant reaction rate (CRR) temperature programs made it possible to employ another approach too, when the preexponential factor was allowed to vary from experiment to experiment. The latter approach allows a formal kinetic description of the differences in the thermal deactivation of the samples caused by different thermal histories as well as of some inevitable systematic errors of the TGA experiments. The evaluations were carried out by both approaches, and the results were compared. The evaluations were based on 12 experiments. As a test, each evaluation of the study was repeated with only 8 experiments. The results of the latter test calculations indicated that the information content of the employed experiments is sufficient for the evaluation approaches of this work."

BioCarbUp at SDEWES

Two BioCarbUp works have been presented at 16th Conference on Sustainable Development of Energy, Water and Environment Systems, 10-15 October 2021, Dubrovnik, Croatia:
1) Liang Wang, Lorenzo Riva, Pietro Bartocci, Zsuzsanna Czégény, Øyvind Skreiberg, Henrik Kofoed Nielsen (2021). Study on Densification of Biocarbon for Metal Production Application.
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 ISGA-7

One BioCarbUp connected work has been presented at 7th International Symposium on Gasification and its Applications, 27-30 September 2021, online:
Aekjuthon Phounglamcheik, Ricardo Vila, Liang Wang, Norbert Kienzl, Markus Broström, Kerstin Ramser, Øyvind Skreiberg, Kentaro Umeki (2021). Effect of pyrolysis conditions and feedstocks on char gasification reactivity.

BioCarbUp at Infacon XVI

One BioCarbUp work has been presented at Infacon XVI: International Ferro-Alloys Congress, 27-29 September, Trondheim, Norway:

Hamideh Kaffash, Merete Tangstad (2021). The effect of densification on compressive strength of charcoal. A corresponding article has been published in proceedings.

BioCarbUp in Bioresource Technology

One BioCarbUp work has been published in Bioresource Technology:

Bence Babinszki, Zoltán Sebestyén, Emma Jakab, Luca Kőhalmi, Janos Bozi, Gábor Várhegyi, Liang Wang, Øyvind Skreiberg, Czégény Zsuzsanna (2021). Effect of slow pyrolysis conditions on biocarbon yield and properties: Characterization of the volatiles. The abstract is given below.

"Slow pyrolysis of spruce and birch was performed at various heating programs and conditions in a horizontal quartz tube reactor heated by an electric furnace. The effects of feedstock and carbonization conditions on the yield of biocarbon, liquid and gaseous products were studied. The thermal properties, volatile matter (VM) content and the evolution profiles of volatiles from the biocarbons were characterized by thermogravimetry/mass spectrometry. The composition of volatiles was analyzed in detail by pyrolysis–gas chromatography/mass spectrometry. Increased char yield was observed when staged pyrolysis program, low purging flow rate or covered sample holder were applied. Spruce produced more charcoal than birch due to the higher lignin content of softwood. The amount and the evolution profiles of the main gaseous products were similar from spruce and birch biocarbons prepared under the same conditions. The relative amount of aromatic and polyaromatic compounds in VM drastically decreased with increasing carbonization temperature."

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."

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, Zsuzsanna Czégény, Roman Tschentscher, Øyvind Skreiberg. Characterization of Liquid By-products from Slow Pyrolysis of Woody Biomass. Accepted for presentation at E2DT, 23-26 October 2022, Milan, Italy.

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A corresponding article has been accepted for publication in proceedings.

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Gøril Jahrsengene, Stein Rørvik, Anne Støre, Liang Wang, Øyvind Skreiberg (2022). Bio-Binders and its Carbonization and Interaction with Petroleum Coke during Baking. Light Metals 2022: Electrode Technology for Aluminum Production, pp. 883-889.

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