Biomass upgrading for improved combustion processes

CenBio Final Conference

Ås, Norway

13-14 March 2017

Øyvind Skreiberg

Chief Scientist / Dr. ing.

SINTEF Energy Research

Key projects

BioCarb+ Enabling the biocarbon value chain for energy

Biomass → Logistics → Biocarbon production → BIOCARBON → Conversion → Clean energy

Some biomass upgrading options

- ✓ Drying
- ✓ Homogenization
- ✓ Sorting, fractionation
- ✓ Size reduction, grinding
- ✓ Blending
- ✓ Additives
- ✓ Pelletisation, briquetting
  - ✓ Handling, storage and transport
- ✓ Anaerobic digestion
- ✓ **Thermal upgrading**

Goal:

Improve the biomass properties with respect to the downstream value chain

Some thermal upgrading processes for biomass

	Moderate heat treatment, High solid material yield	Severe heat treatment, focus on biocarbon	Severe heat treatment, focus on biooil
N2	Dry torrefaction / mild pyrolysis	Dry carbonization	Fast/flash pyrolysis, biocarbon as rest product
Water	Wet torrefaction / hydrothermal pretreatment	Wet carbonization	Liquefaction, biocarbon as rest product
Steam	Steam explosion		

Moderate increase in C content and heating value for the solid product

High C content and high heating value biocarbon

The products from a specific type of biomass treated with the different methods will have highly varying properties!

CenBio

CenBio host institution: NMBU
CenBio lead: SINTEF

Management and coordination — SP0/SINTEF

Biomass supply and residue utilization SP1/NFU	Conversion mechanisms SP2/SINTEF	Conversion technologies and emissions SP3/SINTEF	Knowledge transfer and innovation SP5/NTNU
Feedstock WP1.1	Combustion WP2.1	Small-scale WP3.1	Bioenergy graduate school WP5.1
Logistics WP1.2	Gasification WP2.2	District heat WP3.2	Knowledge transfer and dissemination WP5.2
Biomass and residue characteristics and quality WP1.3	Pyrolysis WP2.3	Heat and power WP3.3	Innovation management WP5.3
Residues upgrading and use WP1.4	Anaerobic digestion WP2.4	Emissions WP3.4	
	KMB STOP: Torrefaction WP2.5		

Sustainability assessments — SP4/NMBU

Life cycle assessment (LCA) WP4.1	Ecosystem management WP4.2	Cost assessment and marked analysis WP4.3

Value Chain Assessment — SP6/NTNU

Environment and cost characteristics — WP6.1

BioCarb+

Enabling the biocarbon value chain for energy

- Partners and collaborators:
  - 11 partners, 4 research and 7 industry
  - Collaborative partners:
    - Hungarian Academy of Sciences
    - Gabor Varhegyi, Hungary
    - Colomba Di Blasi, University of Naples
    - Juha Nurmi, Metla, Finland
- Duration: 4 years, 01.2014-12.2017
- Budget: 5 MNOK/year (20 total)
- Type: KPN (formerly KMB – 80% RCN financed)

STOP

Stable operating conditions for biomass combustion plants

- Partners and collaborators:
  - CenBio industry partners, 2 research partners
  - Collaborative partners:
    - Hungarian Academy of Sciences
    - NMBU
- Duration: 4 years, 01.2010-12.2013
- Budget: 3.5 MNOK/year (14 total)
- Type: KMB (now KPN – 80% RCN financed)

Torrefaction

Torrefaction is a thermal fuel pretreatment technology which allows moisture and low weight organic volatile components of biomass to be removed, producing a hydrophobic solid product with an increased energy density (on a mass basis) and greatly increased grindability.

TOP = TOrrefied and Pelletised biomass

Kilde: Zwart (2007)

Three phases are formed:

- solid product of brown/black colour
- acidic aqueous phase of yellowish colour
- permanent gases such as carbon monoxide and carbon dioxide

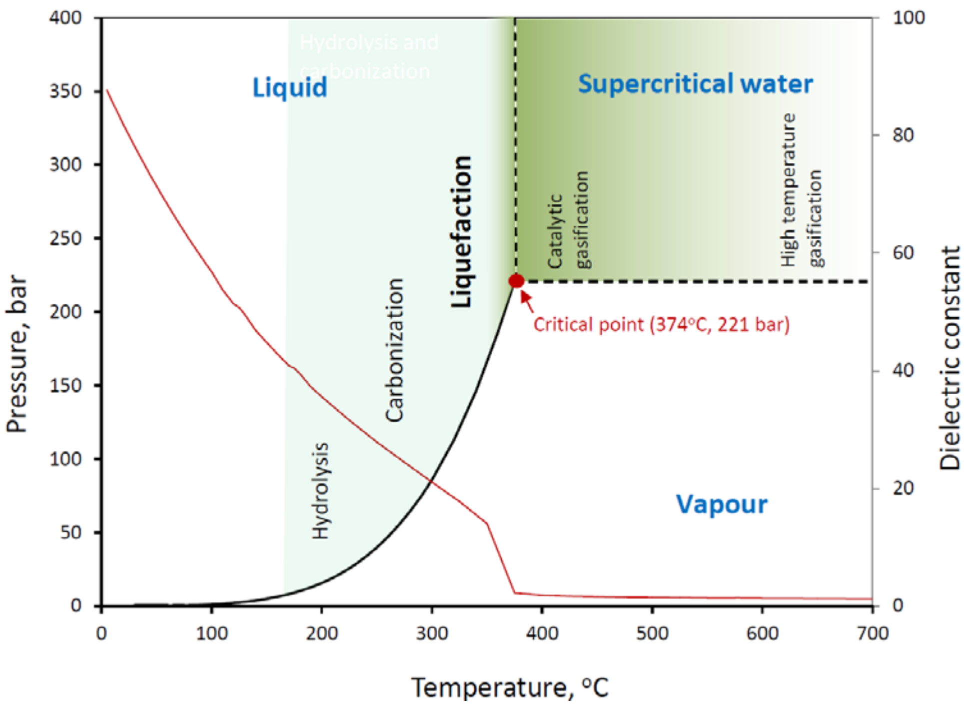
Torrefaction

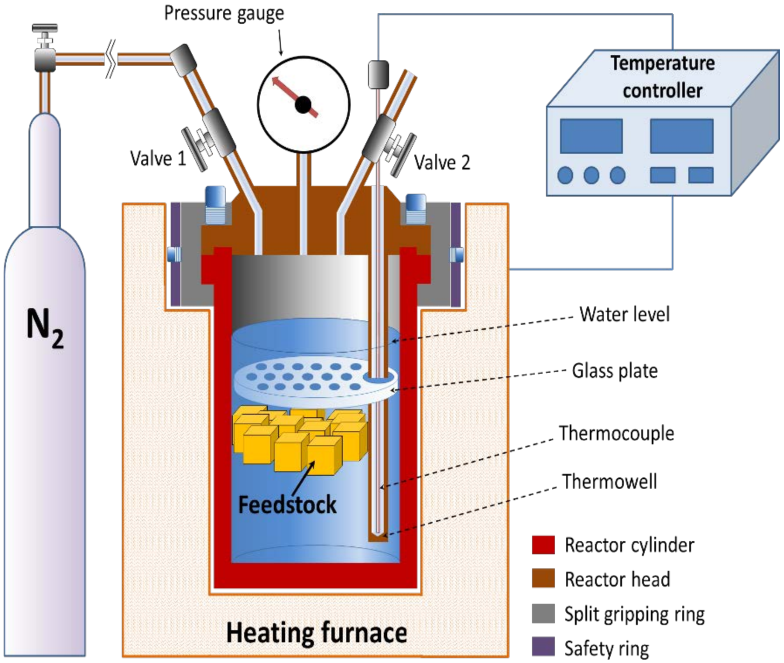
- Gives fuel
  - with high energy density, when compressed
  - which is water repellant (hydrophobic) and has very good storage stability
  - which require little grinding energy
  - which has good combustion properties
  - which contain about 90% of the energy, but only 70% of the mass of the original fuel

- Torrefied fuel can
  - be produced from different types of biomass
  - be used in pulverized fuel burners
  - be used as pulverized fuel in entrained flow gasifiers
  - be transported more economically over large distances as pellets
  - be used as pellets with improved properties in common pellets applications
  - be easily mixed with other fuels
  - give plants with simpler fuel feeding, design and operation

Wet torrefaction – additional benefits

- Enable using low cost biomass as feedstock
- No need of pre-drying step
- Faster
- Valuable by-products: chemicals from aqueous phase





STOP

- **Why a project that is looking at stable combustion conditions for biomass and biomass residues combustion plants?**
  - Fuel quality is a major challenge in biomass combustion plants
  - Varying fuel quality puts strong demands on plant design and operation
  - Use of more challenging biomass fuels like demolition wood, GROT, agricultural residues and sludge gives opportunities for reduced fuel costs
  - New fuel upgrading methods for biomass will open up new opportunities for biomass fuels producers, distributors and users

STOP

- **Main goal: Development of new strategies for improved operating conditions control in biomass and biomass residues combustion plants through:**
  - The utilization of more homogenous fuel with minimized season variation
  - Optimized fuel in terms of pollutant emissions
  - Improved fuel quality through torrefaction

(from the project description)

STOP

Sub objectives:

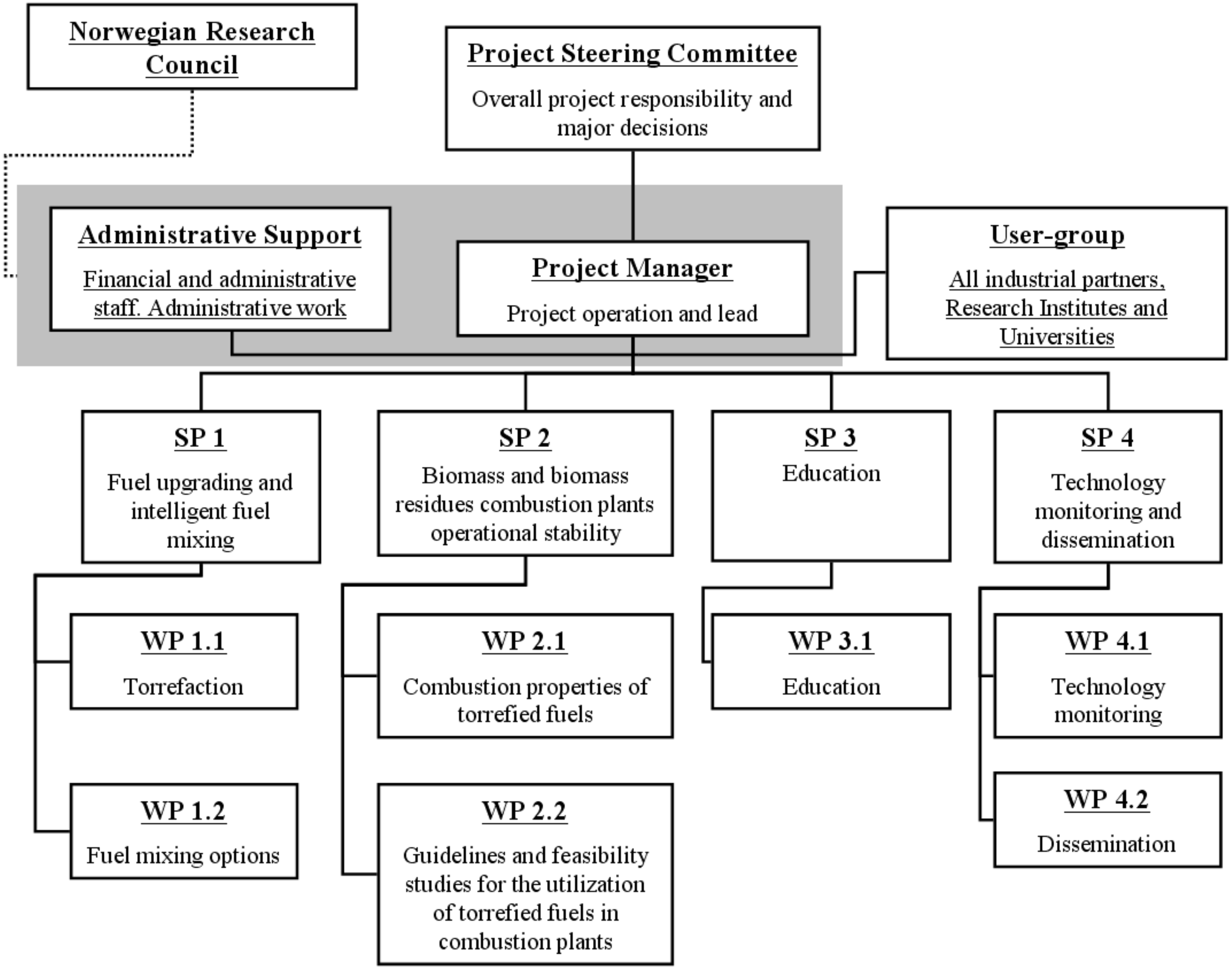
A thermal pre-treatment step for the raw fuel in order to:

- Increase stable operating conditions in biomass and biomass residues combustion plants
- Increase availability, reduce O&M costs and increase cost-efficiency in combustion plants
- Develop and extensive test of laboratory-scale torrefaction research setup
- Study in details torrefaction of biomass and biomass residues and mixtures thereof for the production of improved fuels
- Test torrefied fuels and mixtures thereof in small-scale combustion units
- Identify the combinations of optimum fuels, and fuel mixtures, for improved stable operational conditions
- Educate MS and PhD candidates
- Monitor technology including dissemination to industry

(from the project description)


STOP

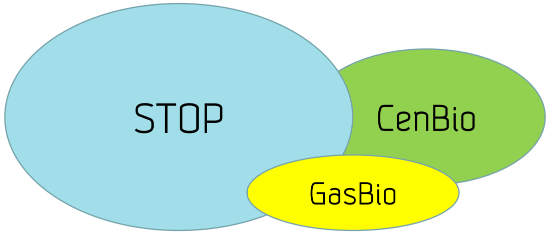
STOP

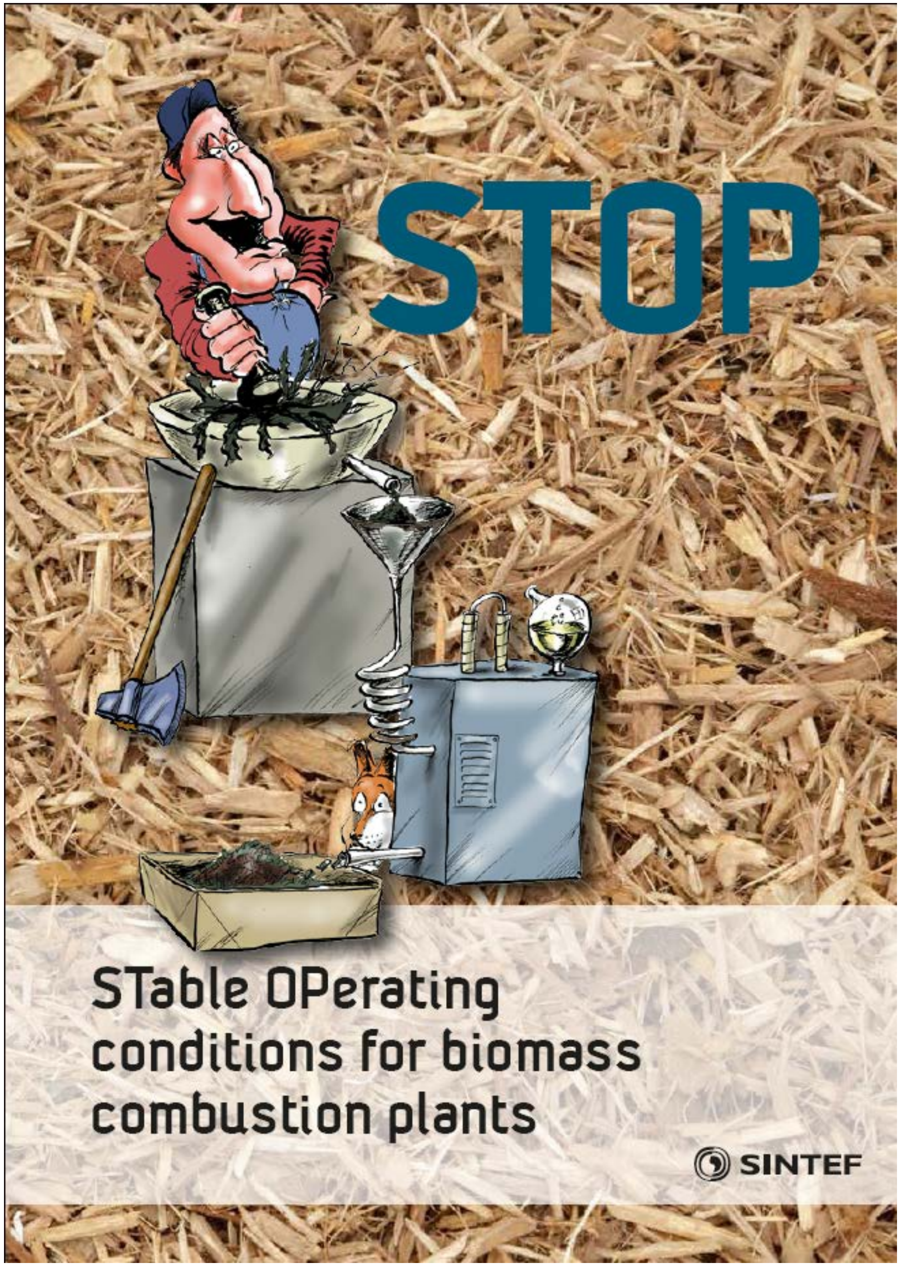

Norwegian Research Council
Project Steering Committee
Overall project responsibility and major decisions
Administrative Support
Financial and administrative staff. Administrative work
Project Manager
Project operation and lead
User-group
All industrial partners, Research Institutes and Universities
SP 1
Fuel upgrading and intelligent fuel mixing
SP 2
Biomass and biomass residues combustion plants operational stability
SP 3
Education
SP 4
Technology monitoring and dissemination
WP 1.1
Torrefaction
WP 1.2
Fuel mixing options
WP 2.1
Combustion properties of torrefied fuels
WP 2.2
Guidelines and feasibility studies for the utilization of torrefied fuels in combustion plants
WP 3.1
Education
WP 4.1
Technology monitoring
WP 4.2
Dissemination

Activities overview

Dry torrefaction	Wet torrefaction

- Fuel properties
- Operational challenges
- Fuels: hardwood (birch), softwood (spruce), branches and tops (GROT)
- Torrefaction in macro-TGA
- Torrefaction in torrefaction reactor
- Wet torrefaction
- TGA
- Torrefaction kinetics
- Pyrolysis kinetics of torrefied material
- Combustion kinetics of torrefied material
- Gasification kinetics of torrefied material
- Combustion performance of torrefied pellets
- Pelletability and pellet quality of torrefied material
- System analysis and process integration
- Techno-economics and cost-efficiency





See also CenBio Final Report

You are here: STOP / **Publications**

- News
- Project overview
- Partners
- Links
- Publications

Publications

This section will contain information about material published by STOP.

STOP handbook

- Newsletter 2-2013
- Newsletter 1-2013
- Newsletter 2-2012
- Newsletter 1-2012
- Newsletter 2-2011
- Newsletter 1-2011
- Newsletter 1-2010

STOP in the media

Øyvind Skreiberg, Roger A. Khalil (2015). Oppvarmet skogsavfall gir mer energi (Roasted forest waste gives more energy). blog.sintefenergy.com

Svein Tønseth (2013). Topp biobrensel fra skogbunnen (Top-class biofuel from the depths of the forest). Gemini, 9 April 2013. Reproduced on forskning.no, sciencenordic.com.

CenBio (2013). The "dream fuel" is already here! Bioenergy Innovation Centre (CenBio), in Best of CenBio.

Svein Tønseth (2013). The "dream fuel" is already here! Bioenergy Innovation Centre (CenBio), in YEAR Newsletter nr. 15, January 2013.

Publications and presentations

Quang-Vu Bach, Øyvind Skreiberg. Pyrolysis kinetics of wet-torrefied forest residues. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

L. Wang, E. Barta-Rajnai, Ø. Skreiberg, R. Khalil, Z. Czégény, E. Jakab, Zs. Barta, M. Grønli. Impact of Torrefaction on Woody Biomass Properties. Accepted for publication in Energy Procedia.

E. Barta-Rajnai, L. Wang, Z. Sebestyén, Zs. Barta, R. Khalil, Ø. Skreiberg, M. Grønli, E. Jakab, Z. Czégény. Effect of Temperature and Duration of Torrefaction on the Thermal Behavior of Stem Wood, Bark, and Stump of Spruce. Accepted for publication in Energy Procedia.

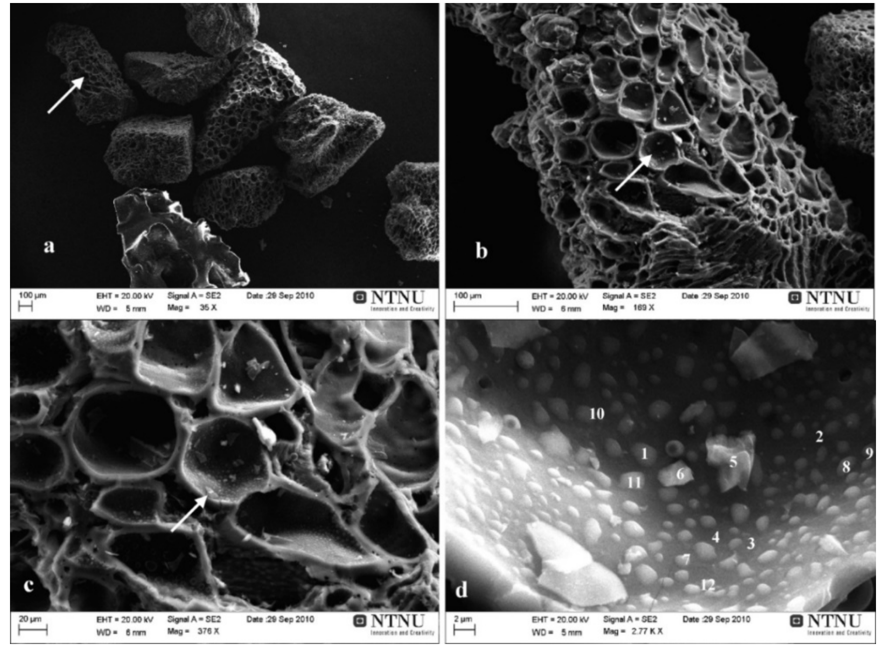
Khanh-Quang Tran, Aksel Junge Klemsdal, Wennan Zhang, Judit Sandquist, Liang Wang, Øyvind Skreiberg. Fast hydrothermal liquefaction of native and torrefied wood. Accepted for publication in Energy Procedia.

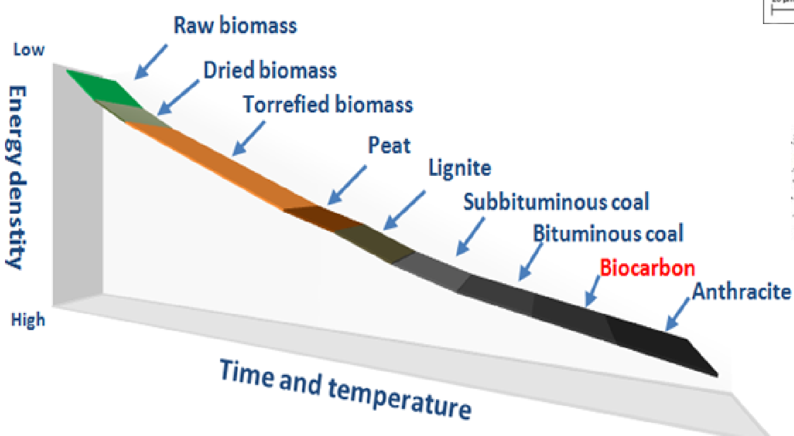
E. Barta-Rajnai, L. Wang, Z. Sebestyén, Zs. Barta, Ø. Skreiberg, M. Grønli, E. Jakab, Z. Czégény (2016). Effect of torrefaction on the thermal behavior of stem wood, bark, and stump of Norway spruce. The Sixth McDonnell Academy International Symposium, 22-25 September, Brisbane, Australia.

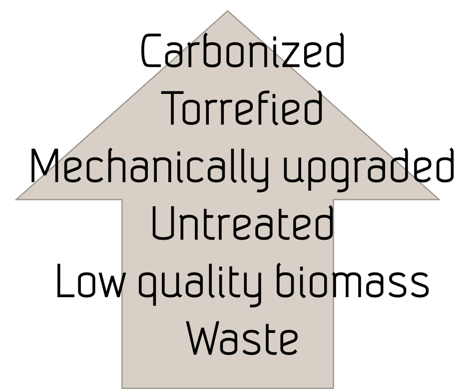
L. Wang, E. Barta-Rajnai, Z. Czégény, E. Jakab, G. Várhegyi, R. Khalil, Ø. Skreiberg, M. Grønli (2016). Impact of torrefaction on fuel properties of woody biomass. Workshop on Aviation biofuels through biomass gasification, 25 May 2016, Trondheim, Norway.

http://www.sintef.no/stop

What is biocarbon?







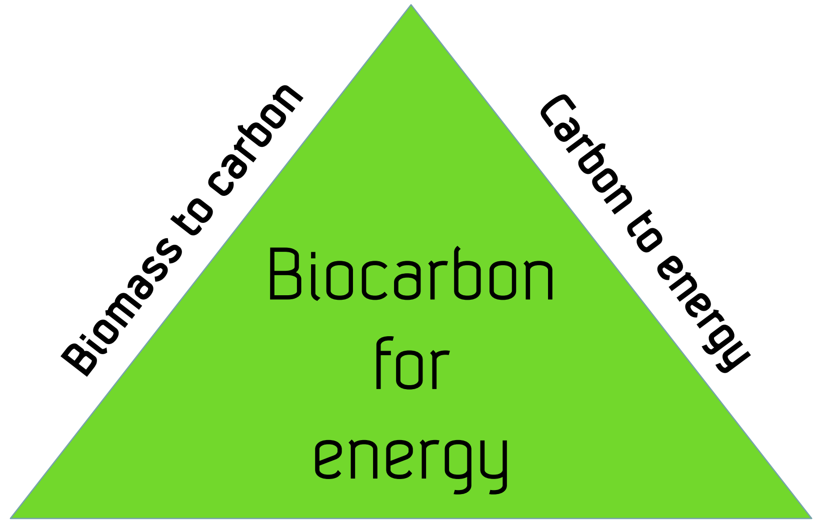
Why biocarbon?

- Highest heating value, and energy density when compressed
- Easy to grind to small and spherical particles
- High reactivity
- Hydrophobic
- No bacteriological degradation
- Reduced logistics costs
- Reduced plant costs (investments and operation)
- Most stable combustion conditions
- Least emission fluctuations
- Lower NOx and SOx emissions compared to coal
- Less ash than in fossil coal

Biocarbon is the ultimate solid biomass fuel, as well as an attractive reductant in metallurgical processes

Where should we use biocarbon?

Metallurgical processes



Environment and climate friendly

Reductant for metal oxides, also for silicon production, for use in **solar cells**

Heat *and* ***power***

Why is research needed?

- **Different types of biomass** gives different biocarbon yield and quality
- **Different carbonization technologies** (and process conditions) also
- **Different end user areas** have different quality demands
- This is a challenge but also a strength!
- The trick is to use the **right biomass** resource for production of biocarbon with **acceptable end user properties**, in a **sustainable** manner

Optimization of all elements in the value chain!

Forest:
- Wood species
- Stem wood
- Branches and tops
- Roots

Production:
- Carbonization technology
- Process parameters (temp., time, pressure, etc.)
- Product form

End use:
- Reductant
- Combustion
- Gasification
- etc.

Logistics

Why BioCarb+?

OVERALL OBJECTIVE

The overall objective of BioCarb+ is **development of new strategies for use of low-grade biomass, pulpwood and energy wood resources for BC production for raw material for industrial applications (reduction agent / metallurgical coke) and conversion for energy purposes.**

SUB-OBJECTIVES (over the 4-year period)

- New or improved **biomass harvesting and logistics solutions**, with special attention to forest residues, but also pulpwood and energy wood (including hardwood), and their properties
- New or improved **biocarbon production solutions** through development or improvement of biomass pretreatment methods, biocarbon production processes and applications and biocarbon logistics solutions
- New or improved **biocarbon conversion solutions** through development or improvement of biocarbon conversion applications with focus on high energy efficiency and low emissions, and biocarbon properties for industrial applications
- Efficient utilisation of by-products from the biocarbon production process to improve overall economy and improve sustainability (CO_2-footprint) of biocarbon production and utilisation
- **Education** of highly skilled candidates within this area and training of industry partners
- Monitoring of activities and state-of-the-art within this area and **dissemination** of knowledge to the industry partners, and other interested parties where applicable

The anticipated results of the project are **reduced harvesting and logistics costs for low-grade biomass resources**, **maximised BC yield and quality** in the BC production process and **maximised energy efficiency** and **minimised emissions** in the BC end-use applications.

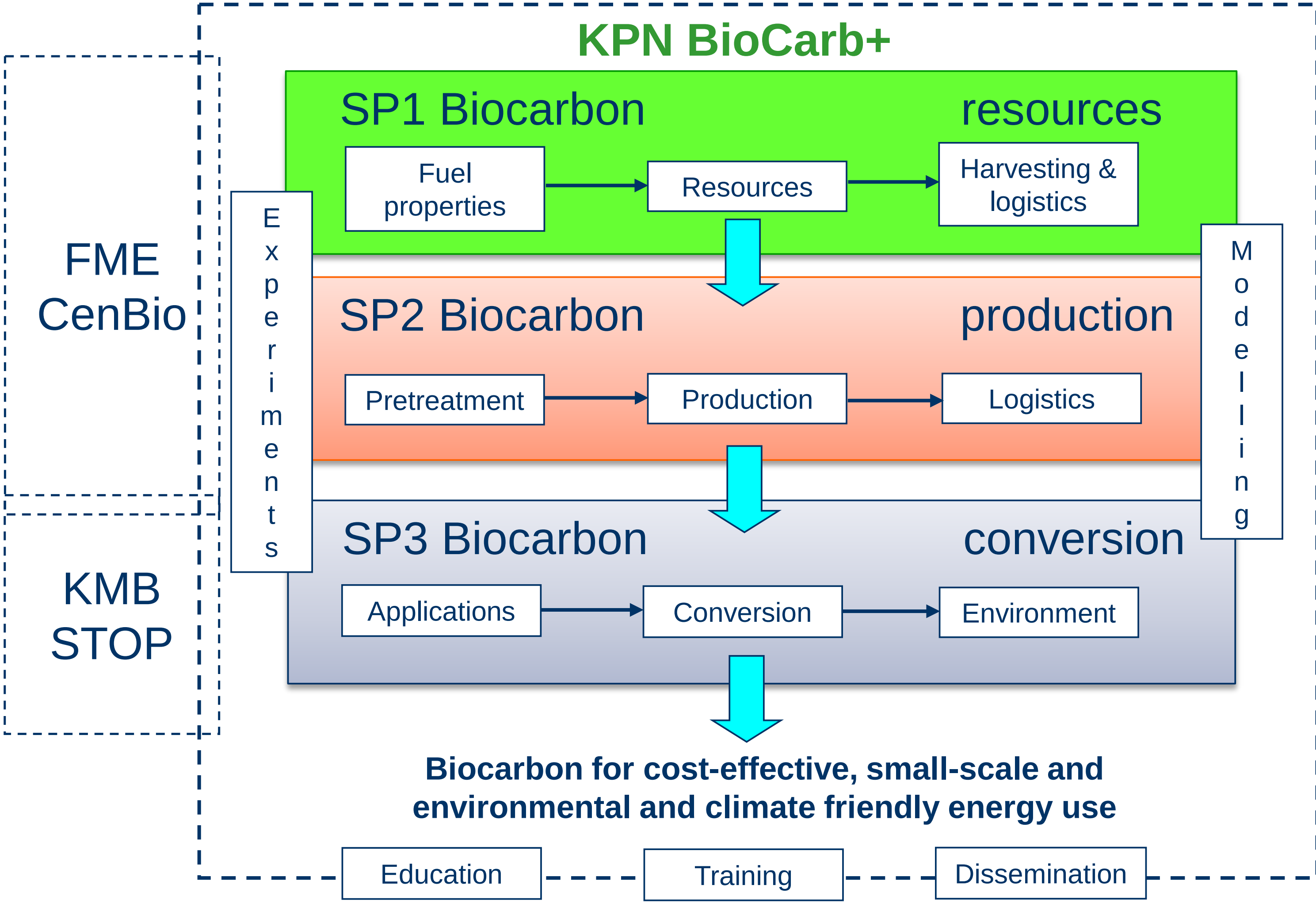
Forest utilization

New or improved solutions/ processes

High biocarbon and fixed carbon yield

Optimal biocarbon end use

BioCarb+

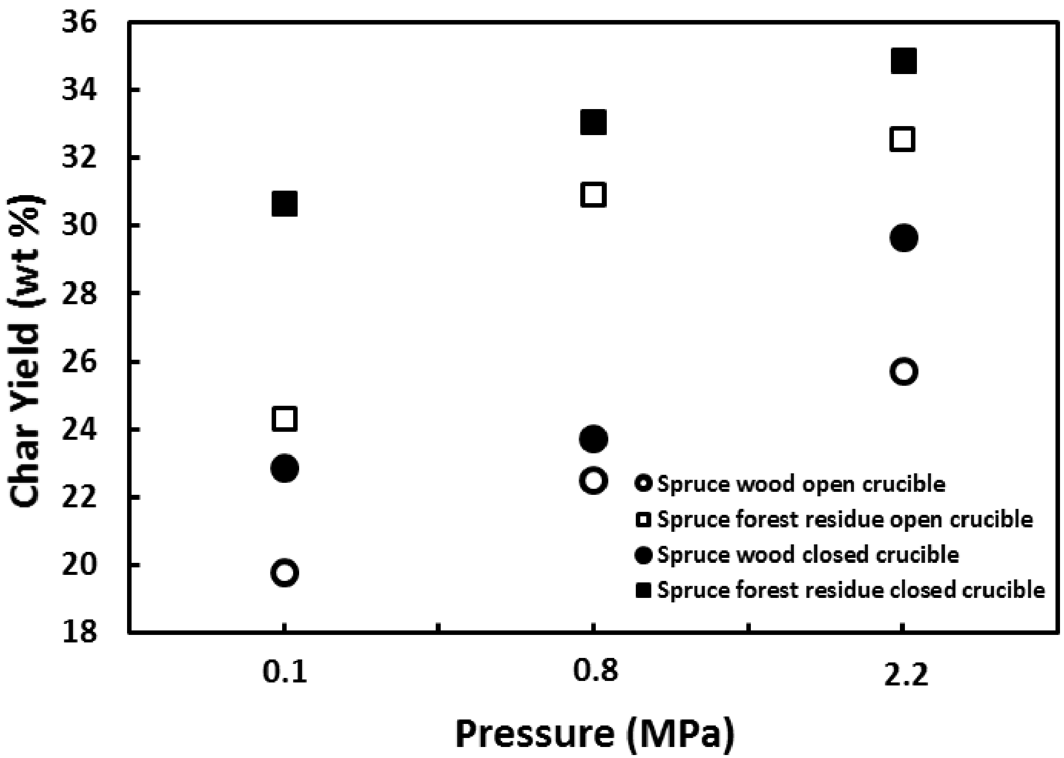

KPN BioCarb+
SP1 Biocarbon resources
Fuel properties
Resources
Harvesting & logistics
SP2 Biocarbon production
Pretreatment
Production
Logistics
SP3 Biocarbon conversion
Applications
Conversion
Environment
Experiments
Modelling
FME CenBio
KMB STOP
Biocarbon for cost-effective, small-scale and environmental and climate friendly energy use
Education
Training
Dissemination

BioCarb+ partners

Both research- and industry partners from the resource to the end user side

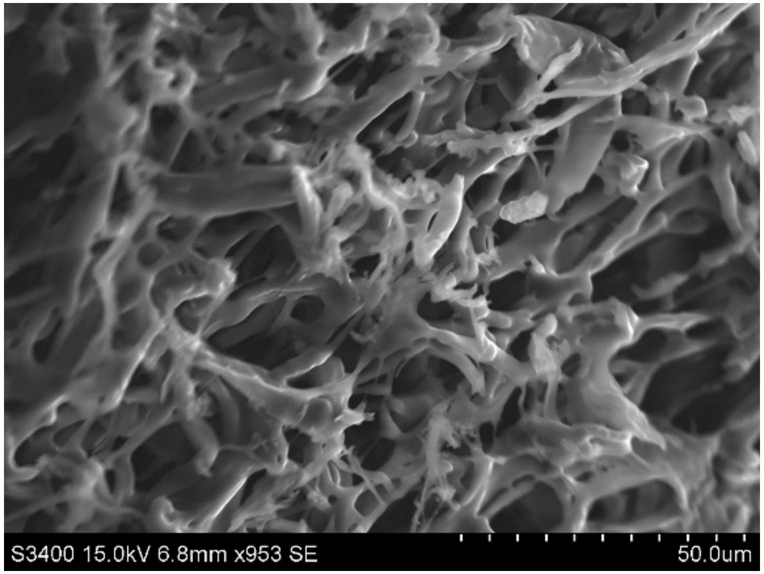
- SINTEF Energy Research AS
- Norwegian University of Science and Technology
- Norwegian Institute of Bioeconomy Research
- Hawaii Natural Energy Institute at University of Hawaii at Manoa
- Elkem AS, Department Elkem Technology
- Norsk Biobrensel AS
- AT Skog SA
- Eyde-nettverket
- Saint Gobain Ceramic Materials AS
- Eramet Norway AS
- Alcoa Norway ANS

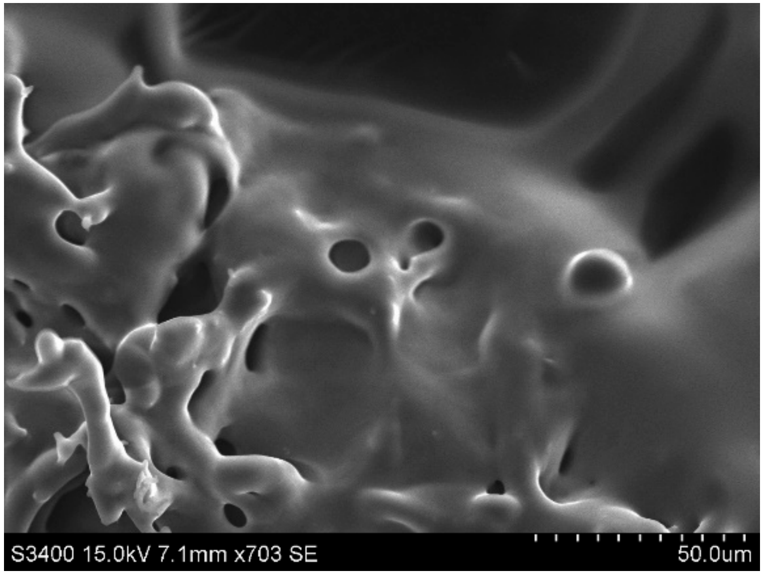
Yes, it is possible



Effects of pressure on spruce wood and spruce forest residue char yield

Zooming in

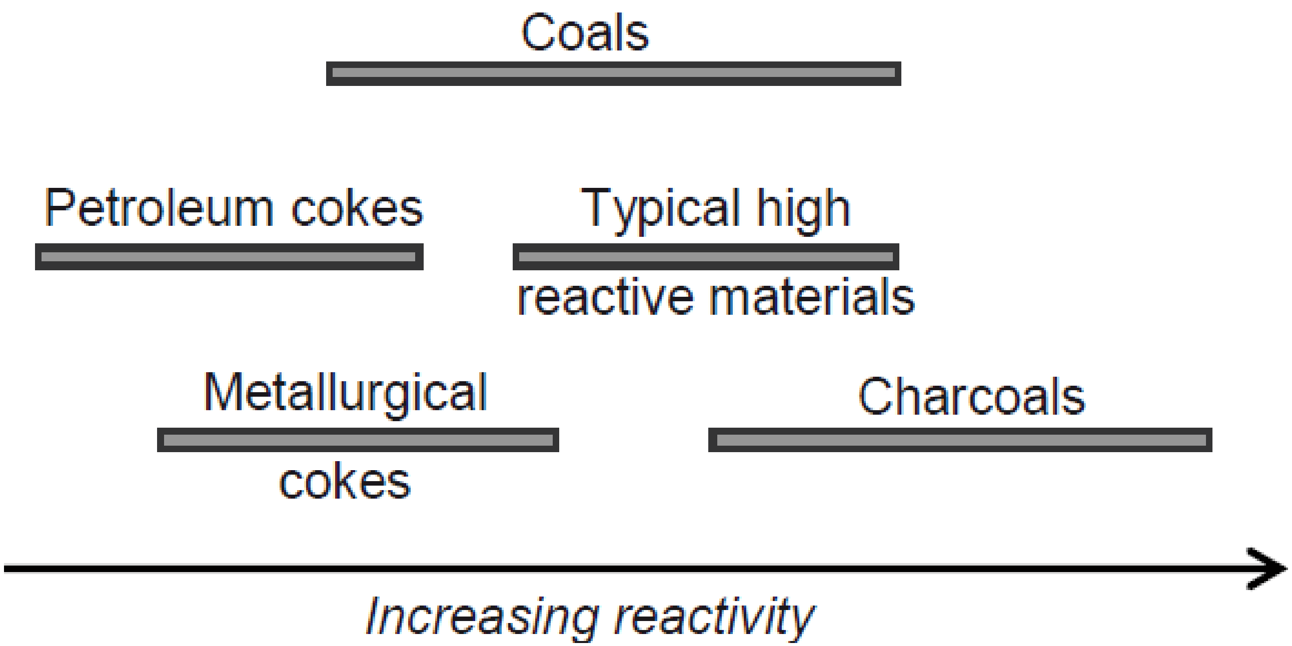




Scanning electron microcopy (SEM) image of cellulose char produced in (a) open crucible and (b) crucible covered by a lid

Secondary reactions give increased biocarbon yield but also structural changes and altered properties

Reactivity is high, but can be influenced



Myrvågnes (2008)

High reactivity is wanted in combustion processes

A number of parameters influence the reactivity

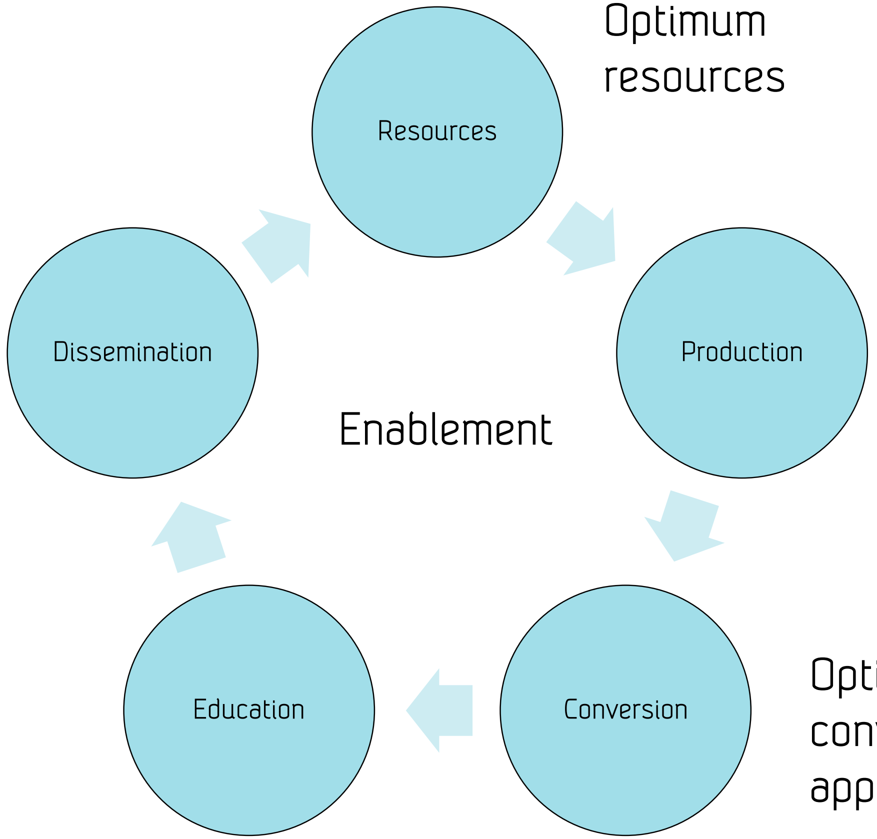
Enabling the biocarbon value chain for energy (BioCarb+)

Summary

Deliverables, education and dissemination

Optimum
resources

Industry
Scientific community
General public



Optimum
production
processes

Students

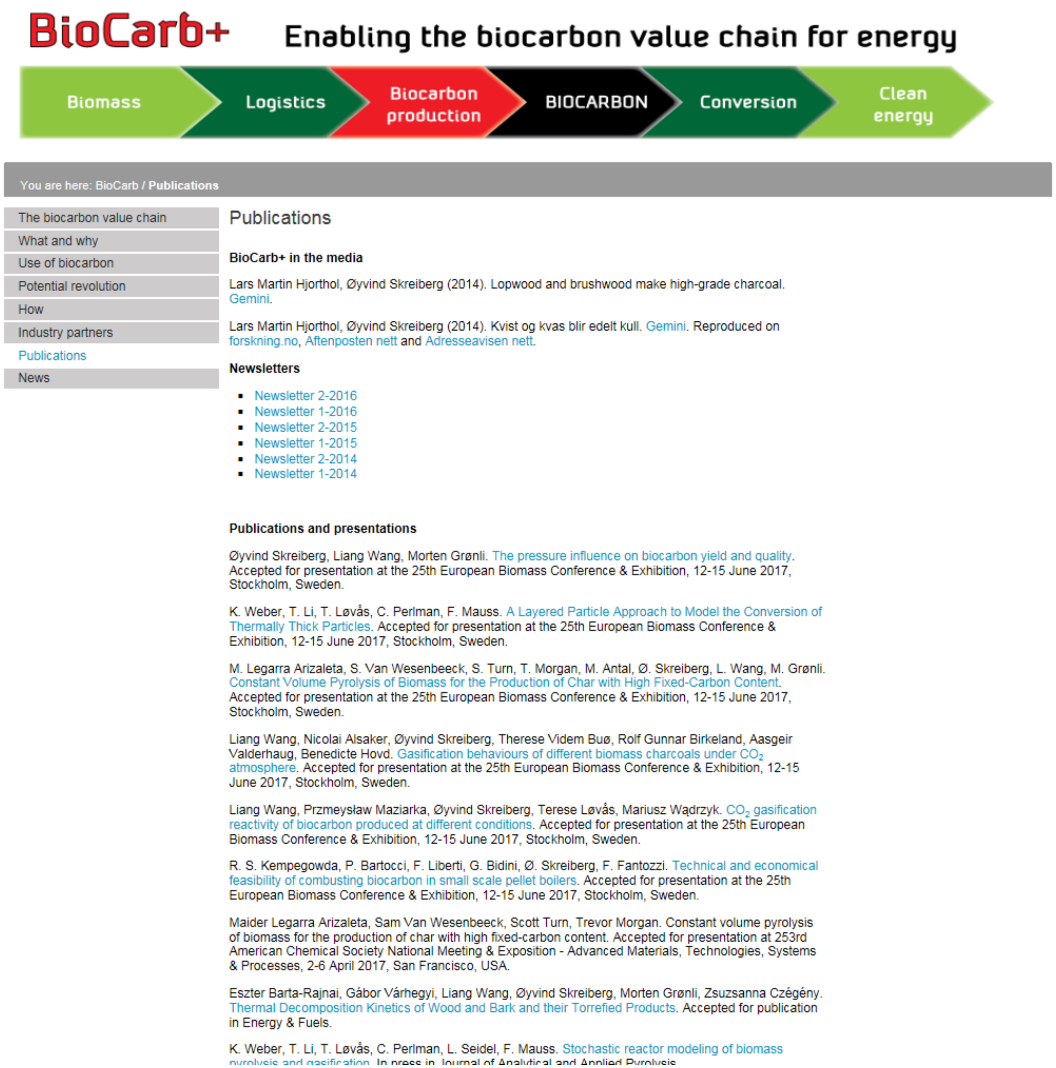
Optimum
conversion
applications

Enabling the biocarbon value chain for energy (BioCarb+)

Key activities:

- Identifying the resource base
- Fuel logistics improvements
- Fuel properties, and their influence on biocarbon production and end-use (general aspect)
- Carbonization technologies
- Influence of carbonization process conditions on biocarbon yields and characteristics
- Pressure (different TGAs, HP-TGA, FC, CV), temperature, holding and residence time (incl. lid/no-lid), pyrolysis modelling
- Biocarbon logistics (focus on biocarbon degradation during storage)
- Biocarbon reactivity (main focus on CO2 reactivity, TGA and Elkem setup, fuel properties and carbonization process influence, kinetic modelling + combustion reactivity & kinetic modelling)
- Biocarbon end-use, metallurgical industries and their quality requirements (main focus)
- Possibilities for influencing biocarbon reactivity (reducing reactivity)
- Biocarbon end-use, direct energy purposes (as charcoal or pellets, kinetic modelling)
- Techno-economics, connected to metallurgical industries and direct energy use (coupled to ASPEN Plus system simulations)
- Value chain perspective
- Recommendations

Enabling the biocarbon value chain for energy (BioCarb+)



BioCarb+ Enabling the biocarbon value chain for energy

Biomass → Logistics → Biocarbon production → BIOCARBON → Conversion → Clean energy

You are here: BioCarb / **Publications**

- The biocarbon value chain
- What and why
- Use of biocarbon
- Potential revolution
- How
- Industry partners
- Publications
- News

Publications

BioCarb+ in the media

Lars Martin Hjorthol, Øyvind Skreiberg (2014). Lopwood and brushwood make high-grade charcoal. Gemini.

Lars Martin Hjorthol, Øyvind Skreiberg (2014). Kvist og kvas blir edelt kull. Gemini. Reproduced on forskning.no, Aftenposten nett and Adresseavisen nett.

Newsletters

- Newsletter 2-2016
- Newsletter 1-2016
- Newsletter 2-2015
- Newsletter 1-2015
- Newsletter 2-2014
- Newsletter 1-2014

Publications and presentations

Øyvind Skreiberg, Liang Wang, Morten Grønli. The pressure influence on biocarbon yield and quality. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

K. Weber, T. Li, T. Løvås, C. Perlman, F. Mauss. A Layered Particle Approach to Model the Conversion of Thermally Thick Particles. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

M. Legarra Arizaleta, S. Van Wesenbeeck, S. Turn, T. Morgan, M. Antal, Ø. Skreiberg, L. Wang, M. Grønli. Constant Volume Pyrolysis of Biomass for the Production of Char with High Fixed-Carbon Content. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

Liang Wang, Nicolai Alsaker, Øyvind Skreiberg, Therese Videm Buø, Rolf Gunnar Birkeland, Aasgeir Valderhaug, Benedicte Hovd. Gasification behaviours of different biomass charcoals under CO_2 atmosphere. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

Liang Wang, Przmeysław Maziarka, Øyvind Skreiberg, Terese Løvås, Mariusz Wądrzyk. CO_2 gasification reactivity of biocarbon produced at different conditions. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

R. S. Kempegowda, P. Bartocci, F. Liberti, G. Bidini, Ø. Skreiberg, F. Fantozzi. Technical and economical feasibility of combusting biocarbon in small scale pellet boilers. Accepted for presentation at the 25th European Biomass Conference & Exhibition, 12-15 June 2017, Stockholm, Sweden.

Maider Legarra Arizaleta, Sam Van Wesenbeeck, Scott Turn, Trevor Morgan. Constant volume pyrolysis of biomass for the production of char with high fixed-carbon content. Accepted for presentation at 253rd American Chemical Society National Meeting & Exposition - Advanced Materials, Technologies, Systems & Processes, 2-6 April 2017, San Francisco, USA.

Eszter Barta-Rajnai, Gábor Várhegyi, Liang Wang, Øyvind Skreiberg, Morten Grønli, Zsuzsanna Czégény. Thermal Decomposition Kinetics of Wood and Bark and their Torrefied Products. Accepted for publication in Energy & Fuels.

K. Weber, T. Li, T. Løvås, C. Perlman, L. Seidel, F. Mauss. Stochastic reactor modeling of biomass pyrolysis and gasification. In press in Journal of Analytical and Applied Pyrolysis

http://www.sintef.no/biocarb

Does it burn better?

- Torrefied material
  - For large scale applications: sure, maybe tweaking of operational parameters
  - For small-scale applications: sure, from tweaking operational parameters to limited design changes, depending on the torrefaction degree

E.g. burning pellets made from torrefied material in a pellet stove works best if the air supply is optimized

- Carbonized material
  - For large scale applications: sure, with tweaking of operational parameters
  - For small scale applications: sure, with major design changes

E.g. burning charcoal in today's wood stoves is not a good solution

What is it all about?

Bioeconomy and global climate

- ✓ Utilization of our increasing biomass resources, preferably in Norway, in an environment friendly and cost-effective way
- ✓ National competence building and industrial development
- ✓ CO2 reduction and sustainability

What shall we use the biomass for in the future?

Acknowledgements

The financial support from the Research Council of Norway and industry through **FME CenBio**, **KMB STOP** and **KPN BioCarb+** is acknowledged, as well as a number of collaborating projects and persons during the last 8 years. None mentioned, none forgotten.

Thank you for your attention!

The Research Council of Norway