Annual Report 2021

NORWEGIAN CENTRE FOR SUSTAINABLE BIO-BASED FUELS AND ENERGY

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

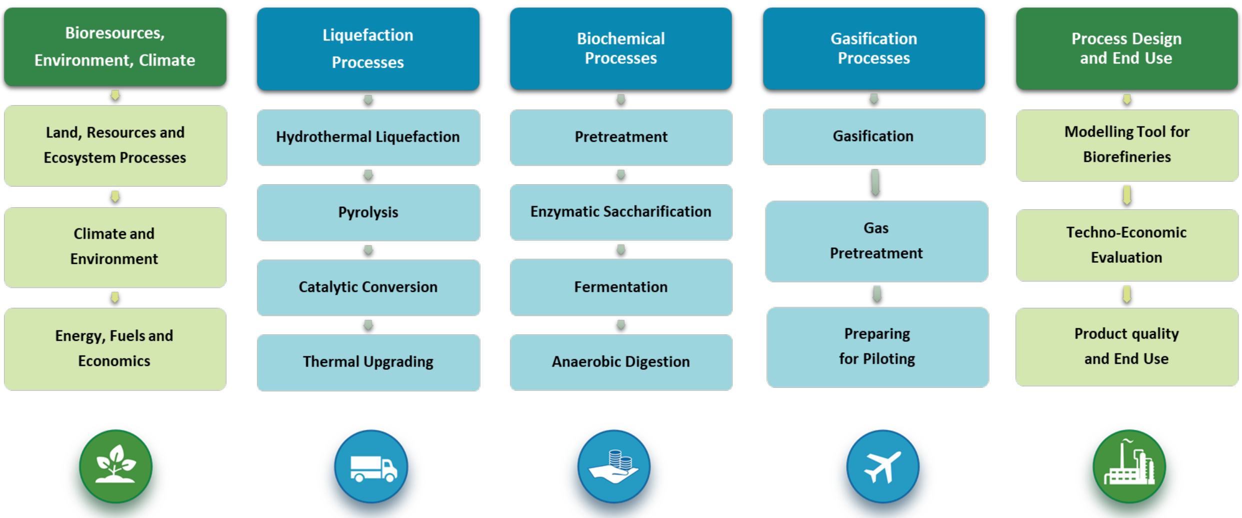
The Research Council of Norway

BIO4FUELS

VISION

ENABLING SUSTAINABLE BIOFUELS PRODUCTION IN NORWAY

Bio4Fuels aims to contribute to the reduction of emissions from the Norwegian transport sector through coordinated research efforts to establish the basis for sustainable routes to advanced biofuels.



Front picture: Cambi's plant at Xiahongmen, China.

Table of Contents

Hall 13 at Silva Green Fuel's demonstration plant at Tofte.
Photo: Silva Green Fuel

From the Chair of the board and Centre leader

2021 was another year that had its own special challenges with partners and activities focussed on balancing the expectations and uncertainties of the transition to more normal interactions. With this backdrop, it was a major milestone that we were able to organise and carry through a physical version of the annual Bio4Fuels days meeting, within a few days before the return to lockdown. 2021 had been planned to be the year of Bio4Fuels second international meeting, but the enjoyment of discussing directly with colleagues in the same room was great compensation, with he visit to Silva Green Fuels HTL Demo unit an additional highlight – showing how far Norway has come from the start of the Centre's activities in 2017.

The timing of the annual meeting also coincided with the end of COP26, following on from the sobering IEA "Net Zero" report earlier on in May. This was a reminder of the importance of the FME Centre's in fostering research within Renewable Energy and also an attempt to quantify the clear role of advanced biofuels as part of the ambitions to reach Net Zero.

With this in mind, Bio4Fuels achieved another milestone in being given the green light from the Research Council's mid-term evaluation to complete the final period of the Centre's eight year's. The evaluation process pointed to areas of potential improvement, which have been rapidly taken on-board and implemented – for which we now see clear benefits.

We acknowledge again the continued support of the Bio4Fuels stakeholders, both industrial and public sector, and the dedication of the research partners.

Ingo Machenbach,
Chair of the Board

Duncan Akporiaye
Centre leader

Summary

The ambition of the Bio4Fuels Centre is to reduce the impact of climate gas emissions from the transport sector through sustainable and economic production of biofuels. Biomass, in particular lowgrade fractions of wood from the forest and waste from agriculture, is a renewable resource that can potentially substitute the use of fossil resources in the transport sector, together with other renewable energy solutions.

There are four main routes identified for the Centre

- Breaking down the biomass to release sugars for use in fermentation to produce bio-alcohols. This can be blended up to certain levels into existing fuels.
- Fermentation of the biomass in the absence of oxygen to produce a biogas. This biogas can be upgraded to methane, liquified or converted to hydrogen for use as fuels in transport.
- Treatment of the biomass at higher temperatures in the absence of oxygen to produce a liquid biooil, which is then upgraded to a relevant biofuel.
- Treatment of the biomass at higher temperatures to convert to a gas, followed by upgrading of the gas to a substitute biofuel.

In addition to the main routes from Biomass to Biofuels, it is also important to convert side streams and biproducts from the processes to products of higher value than fuels. This can be important to help the overall economics of the commercial process.

In addition to the research on the processes, Bio4fuels has a significant activity focused on issues related to the sustainability and economics of biofuel production:

- Improving the technologies and economics of processes for converting biomass to biofuel - Investigating the sustainability and impact of large-scale use of low-grade biomass for biofuels production.
- Evaluating process concepts and testing the quality of the biofuels for existing engines.
- From the operation of the Centre so far, the following areas can be highlighted:
- A successful Kick-off meeting was arranged in February 2017, with an international guest list of industrial presenters from all over Europe and the US. This provided industrial perspective of the state of the art for technology along the whole value chain.
- The Centre has an active and highly competent board, with industry as majority representing the key stakeholders of the value chain.
- The Centre has also established an International Advisory Group with representatives from key research sectors from Finland, United Kingdom and United States.

In 2021 Bio4Fuels completed a successful mid-term evaluation which granted three more years of funding of the Centre. Evaluation panel recommendations included improvement of communication and better involvement of students and stakeholders – areas which are now being implemented.

Bio4Fuels organises annual "Bio4Fuels days" meeting:

- 2017: dedicated to the national strategy, with an excursion to visit the production of Paper (Norske Skog AS) and Biogass (Biokraft AS) at Skogn near Trondheim.
- 2018: taking on an international perspective following the release of the IPCC report, including a visit to the Oslo Biogass production site.

- 2019: Bio4Fuels took the step towards organising a regular international Bio4Fuels days by arranging a conference in Gothenburg together with the UK Supergen and the Swedish f3 centres. With over 200 participants, the conference was overbooked and provided an important platform discussing important issues within the field
- 2020: Virtual conference due to Covid-19. International view on biofuels with speakers from the EU Commission, USA, Canada, Finland and England. Virtual visit to Silva Green Fuels plant at Tofte, Hurum. Approximately 80 participants.
- 2021: Physical meeting in Drammen, including a visit to the Tofte biofuel plant. Dedicated young researcher forum on day one with focus on public acceptance of biofuels. 51 participants.

Bio4Fuels have partners that are active in representing Norway in key tasks within the International Energy Association (IEA). Specifically related to addressing important aspects related to realising climate goals dependent on research within Bioenergy. Through NTNU, Bio4Fuels research partners have been active in leading the efforts and contributing to drafting the latest IPCC report on Climate Change and Land.

Bio4Fuels, together with other FMEs, has charted the effect of Energy research in Norway within renewable energy. This was on behalf of the Norwegian research Council. The Centre is also active in contributing to the background for the debate around the role of biofuels in Norway, through organising and attending Breakfast seminar, organising webinars and responding to specific topics in the media.

Partners in the Centre are also extremely well represented in EU H2020 research program with a very significant portfolio of EU projects as well as active coordination with other Research and Industry partners in the EU.

Bio4Fuels has also carried out a second year "self-evaluation" on behalf of the board. This was the basis for reorganising the Centre's activities towards a stronger focus on the three most important value chains for biofuel production in Norway.

Industry partners in Bio4Fuels have established commercial production of liquified biogas for heavy duty road and ship transport and other partners plan to build commercial plants in Norway, Sweden and Finland for conversion of biomass to liquid drop in biofuels.

BIO4FUELS ORGANIZATION

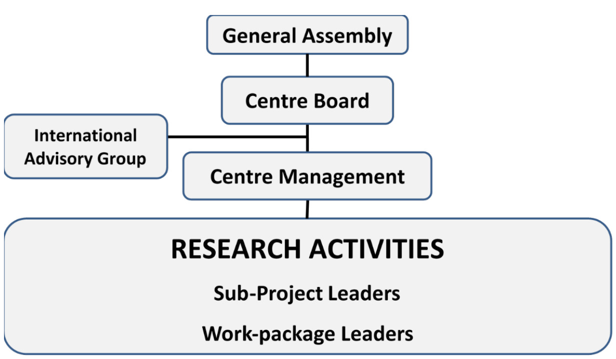
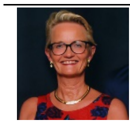


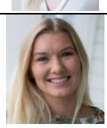
Figure 1*: Organization of the FME Bio4Fuels Centre.*

Centre Board

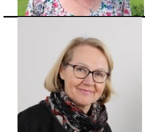
The Bio4Fuels' Board per December 2021:

	**Ingo Machenbach**	**Silva Green Fuel (Statkraft)**	**Chair**
	Tyra Marie Risnes	Viken County Council	Representing Public Partners
	Per Skorge	Norges skogeierforbund	Representing Resource partners
	Kjell Moljord	Equinor	Representing End Users (from Sept 2021)
	Helle Brit Mostad	Equinor	Representing End Users (until Sept 2021)
	Kine Svensson	CAMBI	Representing Technology partners
	Petter Røkke	SINTEF	Centre Leader Institute
	Ågot Aakra	NMBU	Host Institute (until Aug 2021)
	Hans Fredrik Hoen	NMBU	Host Institute (from Aug 2021)
	Terese Løvås	NTNU	R&D partner
	Morten Christian Melaaen	USN	R&D partner*
	*Per Arne Karlsen*	*Research Council of Norway*	*Observer*

The Bio4Fuels' Management Team

	Professor Duncan Akporiaye	SINTEF	Centre Leader
	Professor Svein Jarle Horn	NMBU	Deputy Centre Leader
	Dr. Odd Jarle Skjelhaugen	NMBU	Industrial Liaison
	Dr. Janne Beate Utåker	NMBU	Administrative Manager
	Ann-Solveig Hofseth	NMBU	Financial Officer
	Bente Paulsson	NMBU	Communication Officer
	Liv Axelsen	SINTEF	Communication Officer (until December 2021)
	Haldis Bjerva Watson	SINTEF	Communication Officer (from December 2021)
	Camilla Fløien Angeltveit	NMBU	PhD Representative

The International Advisory group (IAG)

	Advisor	Affiliation	Area of expertise
	Prof. Patricia Thornley	Supergen Bioenergy Hub, Aston University, Birmingham (UK)	Sustainability
	Dean Kristiina Kruus	Aalto University, Otaniemi, Finland (FI)	Biochemical Processes
	Dr. David Dayton	Research Triangle Institute (RTI), NC (USA)	Thermochemical Process

Bio4Fuels Partners and Stakeholders

Research partners in Norway	
NMBU	– The Norwegian University of Life Sciences
SINTEF	– Applied research, technology and innovation
NTNU	– The Norwegian University for Science and Technology
NIBIO	– The Norwegian Institute of Bioeconomy,
IFE	– Institute for Energy Technology
RISE PFI	– Research Institutes of Sweden – Paper and Fiber Institute
USN	– The University of South-East Norway

Bioresource owners	**Main interest**
The Norwegian Farmers Union	Biogas production from agricultural feedstocks
The Norwegian Forest Owners' Federation	Value from forest biomass
The City of Oslo, The energy recovery unit	Biogas production from food waste
Tech./knowledge providers, Norwegian	**Main interest**
Herøya Industry Park	Pilot plant construction
Cambi AS	Plants for biogas production from organic waste
Hyperthermics AS	High temperature biogas production from waste biomass
UMOE AS	Biofuel plant investments and management
Tech./knowledge providers, International	**Main interest**
Biomass Technology Group (NL)	Biomass to liquid (btl) pyrolysis
Johnson Matthey (UK)	Chemical and catalytic processing of bio-feedstocks
Novozymes (DK)	Enzymes for forest based biorefineries
Pervatech (NL)	Membrane and separation systems for organic substrates
Steeper ENERGY (DK)	Hydrothermal liquefaction
Lund Combustion Engineering as (SE)	Consultancy and software on combustion in motors
Biofuel and biochemical producers	**Main interest**
Silva Green Fuel AS	Biodiesel from forest biomass
Biozin AS	Forest based crude oil for biorefineries
Equinor	Feed stock supply, value chains, co-processing
Perstorp Bioproducts AB (SE) / Adesso Bioproducts	High quality biodiesel
Borregaard	Forest-based high value chemicals and bioethanol
Biokraft	Biogas from paper mill side-streams and fish waste
Ecopro AS	Biogas from organic waste
Norske Skog Saugbrugs	Biogas from biorefinery side-streams
Neste (FI)	Biorefinery
Alginor ASA	Seaweed products from a multifunctional biorefinery

Bio4Fuels' Partners and Stakeholders, Continued

Biofuel distributors and end users	Main interest
St1 Norge as	Bioethanol production and distribution in Norway
Volvo Group Trucks Technology (SE)*	Truck engines powered by biofuels
Avinor	BioJetFuels for Norwegian airports
Government and State Partners	**Main interest**
Viken Fylkeskommune	Sustainability, Resource Use, Transport policy, Techn Econ
Innlandet Fylkeskommune	Sustainability, Resource Use, Transport policy, Techn Econ
Trøndelag Fylkeskommune	Sustainability, Resource Use, Transport policy, Techn Econ
Follorådet	Sustainability, Resource Use, Transport policy, Techn Econ
Miljødirektoratet	Sustainability, Resource Use, Transport policy, Techn Econ
Statens Vegvesen	Sustainability, Resource Use, Transport policy, Techn Econ
Innovasjon Norge	Sustainability, Resource Use, Transport policy, Techn Econ
Non-Governmental Organizations / Trade Organizations	**Main Interest**
NOBIO	Bioenergy, Biofuels
Zero	Renewable Energy, Policy

**) Participation in Bio4Fuels ended in 2021.*

Cambi's Plant at Basingstoke, England. Photo: Cambi

SUB-PROJECTS AND WORK-PACKAGES

The Bio4Fuels Centre is divided into 5 sub projects (SPs) and 17 work packages (WPs) as presented in figure 2 below.
From November 2021, *WP5.1 Modelling Tool for Biorefineries* and *WP5.2 Techno-Economic Evaluation* were merged into *WP5.1 Modelling of Biorefineries and Techno-Economic Evaluation / Scale of Economy*.

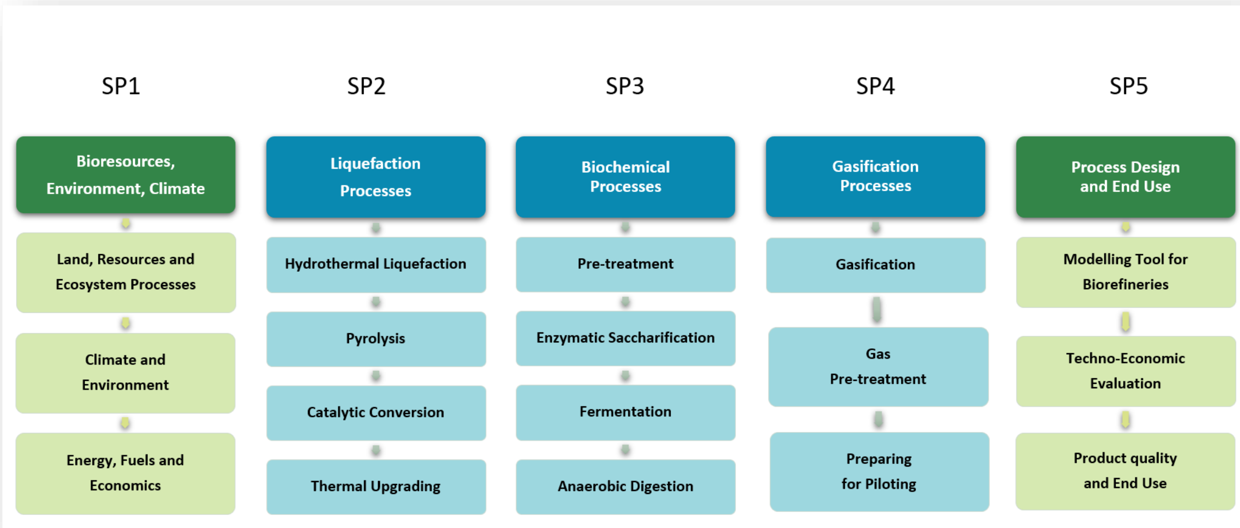


Figure 2: The Organization of Bio4Fuels' Research

Sub Project Leaders

	Name	*Institution*	*Main research area*
	Francesco Cherubini (SP1)	NTNU	Bioresources, Environment and Climate
	Judith Sandquist (SP2)	SINTEF	Liquefaction Processes
	Aniko Varnai (SP3)	NMBU	Biochemical Processes
	Morten Seljeskog (SP4)	SINTEF	Gasification Processes
	Bernd Wittgens (SP5)	SINTEF	Process Design and End Use

Work Package Leaders

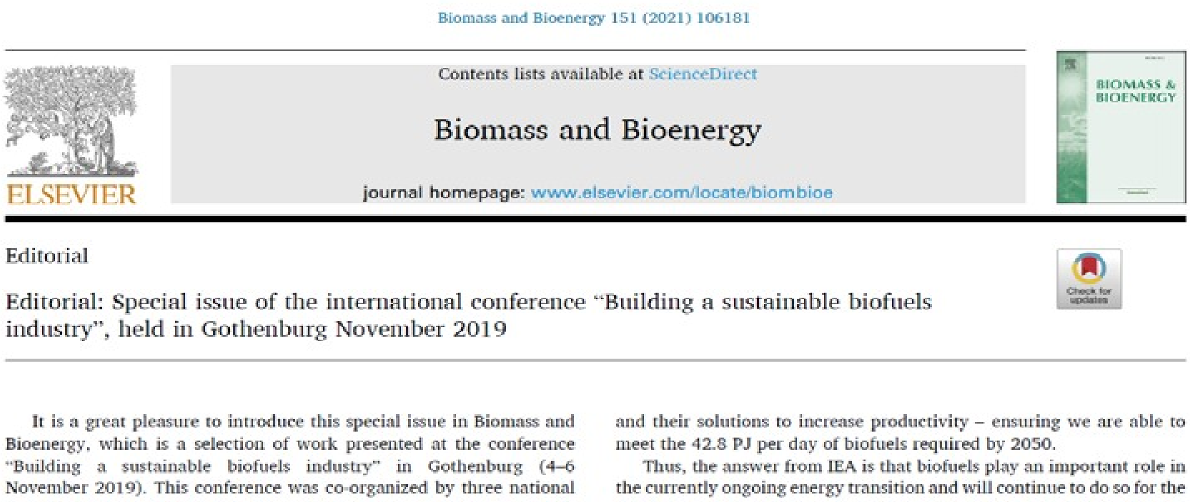
	Name	*Institution*	*Main research area*
	Rasmus Astrup (WP 1.1)	NIBIO	Land, Resources and Ecosystem Processes
	Francesco Cherubini (WP 1.2)	NTNU	Bio-Resources, Environment, Climate
	Torjus Bolkesjø (WP 1.3)	NMBU	Energy, Fuels and Economics
	Kai Toven (WP 2.1)	RISE PFI	Pyrolysis
	Judit Sandquist (WP 2.2)	SINTEF	Hydrothermal Liquefaction
	Roman Tschentscher (WP 2.3)	SINTEF	Thermochemical upgrading of bio oils
	De Chen (WP 2.4)	NTNU	Chemo-catalytic conversion
	Mihaela Tanase Opedal (WP 3.1)	RISE PFI	Pretreatment and Fractionation
	Aniko Varnai (WP 3.2)	NMBU	Enzymatic Saccharification
	Alexander Wentzel (WP 3.3)	SINTEF	Fermentation
 	Michał Sposób (WP3.4 until December 2021) Lu Feng (WP3.4 from 2022)	NIBIO	Anaerobic Digestion and gas upgrading
	Morten Seljeskog (WP 4.1)	SINTEF	Gasification
	Edd Blekkan (WP 4.2)	NTNU	Gas Conditioning
	Klaus Jens (WP 4.3)	USN	Preparing for piloting and up-scale
	Heinz Preisig (WP 5.1 until November 2021)	NTNU	Modelling Tool for Biorefineries
	Bernd Wittgens (WP 5.2)	SINTEF	Techno-Economic Evaluation and Scale of Economy
	Terese Løvås (WP 5.3)	NTNU	Product quality and End Use

HIGHLIGHTS FROM 2021

Research

Special Issue and Editorial in *Biomass and Bioenergy*

- The special issue is based on presentations from Bio4Fuels Days 2019 was published in July 2021
- Includes an Editorial written by Svein Jarle Horn (Bio4Fuels), Marcelle McManus (Supergen) and Ingrid Nyström (f3)
- https://www.sciencedirect.com/journal/biomass-and- bioenergy/special-issue/10ZCG8VXS6H



Biomass and Bioenergy 151 (2021) 106181

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journal homepage: www.elsevier.com/locate/biombioe

Editorial

Editorial: Special issue of the international conference "Building a sustainable biofuels industry", held in Gothenburg November 2019

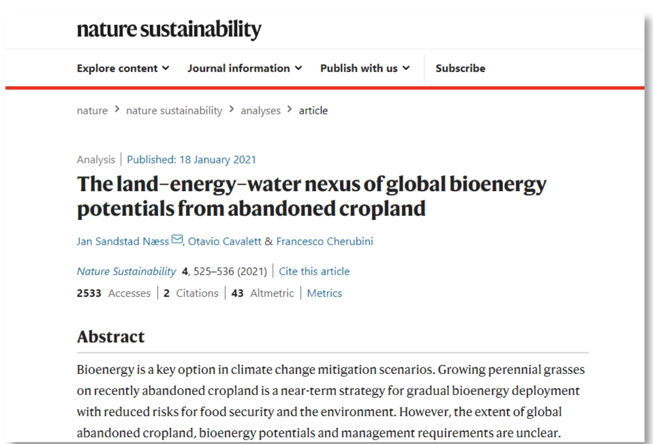
It is a great pleasure to introduce this special issue in Biomass and Bioenergy, which is a selection of work presented at the conference "Building a sustainable biofuels industry" in Gothenburg (4–6 November 2019). This conference was co-organized by three national

and their solutions to increase productivity – ensuring we are able to meet the 42.8 PJ per day of biofuels required by 2050.

Thus, the answer from IEA is that biofuels play an important role in the currently ongoing energy transition and will continue to do so for the

Publication in Nature Sustainability*: The land–energy–water nexus of global bioenergy potentials from abandoned cropland*

Authors: Jan Sandstad Næss, Otavio Cavalett and Francesco Cherubini



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Analysis | Published: 18 January 2021

The land–energy–water nexus of global bioenergy potentials from abandoned cropland

Jan Sandstad Næss, Otavio Cavalett & Francesco Cherubini

Nature Sustainability 4, 525–536 (2021) | Cite this article

2533 Accesses | 2 Citations | 43 Altmetric | Metrics

Abstract

Bioenergy is a key option in climate change mitigation scenarios. Growing perennial grasses on recently abandoned cropland is a near-term strategy for gradual bioenergy deployment with reduced risks for food security and the environment. However, the extent of global abandoned cropland, bioenergy potentials and management requirements are unclear.

More biofuels are needed to counteract climate change. But producing them shouldn't diminish food production or wilderness areas. The solution may be to grow more grass on recently abandoned cropland.

Bioenergy is a key option in climate change mitigation scenarios. Growing perennial grasses on recently abandoned cropland is a near-term strategy for gradual bioenergy deployment with reduced risks for food security and the environment. However, the extent of global abandoned cropland, bioenergy potentials and management requirements are unclear.

Bioenergy potentials are 6–39 exajoules per year (11–68 per cent of today's bioenergy demand), depending on multiple local and management factors. About 20 exajoules per year can be achieved by increasing today's global cropland area and water use by 3 and 8 per cent, respectively, and without production inside biodiversity hotspots or irrigation in water scarce areas.

Detailed monitoring of microbial lipid production by vibrational spectroscopy probes

The oleaginous red yeast *Rhodotorula toruloides* can be used for co-production of lipids and pigments. Vibrational spectroscopies enable detailed monitoring of growth media during the fermentation.

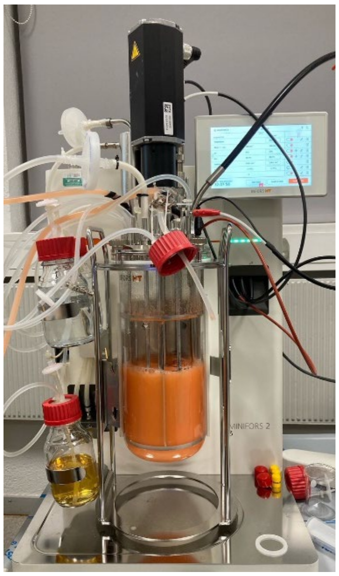


Fig. 1: Fermentation of glucose media by *Rhodotorula toruloides* in 2 L bioreactor.

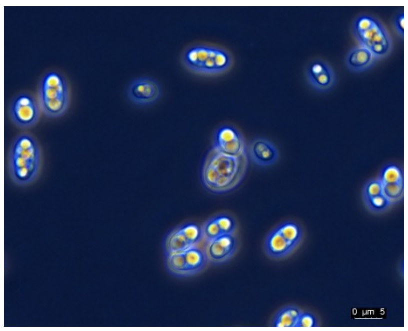


Fig. 2: After 72 hours, yeast cells are full of lipid-storage organelles (lipid bodies).

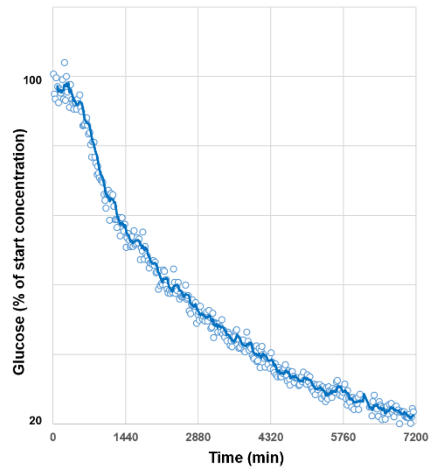


Fig. 3: Utilisation of glucose was monitored by vibrational spectroscopy probe in 20 min intervals.

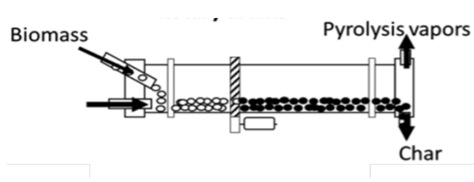
Coproduction of biogas fuel, biocrude and biocarbon

A key task has been to explore the feasibility for coproduction of biogas transportation fuel, biocrude and biocarbon by combining intermediate pyrolysis with anaerobic digestion.

A study on coproduction of biocarbon, biocrude and biogas transportation fuel of Norway Spruce and Birch has been completed and the carbon product yields have been compared with a conventional carbonization process[1].

The study has been carried out in cooperation with the innovation project Pyrogas[2].

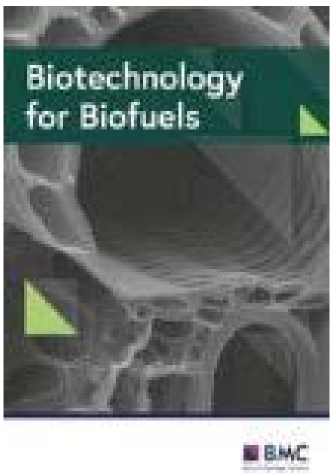
A key result from the study is that more favorable product yields are obtained by combining intermediate pyrolysis and anaerobic digestion as compared to a conventional slow pyrolysis process for biocarbon production.

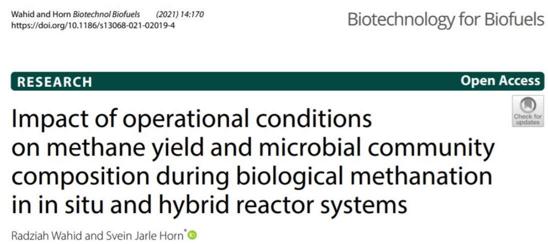


However, the biocrude obtained in the intermediate pyrolysis process needs to extensive upgrading to be used as transportation fuel so alternative applications for the biocrude must be developed. This challenge will be addressed in upcoming work.

[)] *van der Wijst, C., Ghimire, N., Bergland, W. H., Toven, K., Bakke, R., and Eriksen, Ø. (2021). "Improving carbon product yields in biocarbon production by combining pyrolysis and anaerobic digestion," BioResources 16(2), 3964-3977.*
[2)] *RCN 269322 PyroGas – Production of biogas transportation fuel and biocarbon reductant material by combining pyrolysis and anaerobic digestion*

Anaerobic digestion and gas upgrading
New publications on biological methanation:



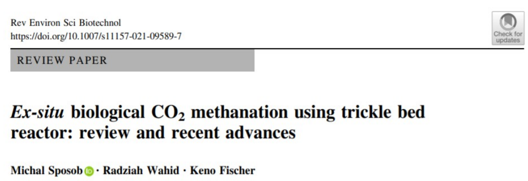

Wahid and Horn *Biotechnol Biofuels* (2021) 14:170
https://doi.org/10.1186/s13068-021-02019-4

Biotechnology for Biofuels

RESEARCH Open Access

Impact of operational conditions on methane yield and microbial community composition during biological methanation in in situ and hybrid reactor systems

Radziah Wahid and Svein Jarle Horn*


Rev Environ Sci Biotechnol
https://doi.org/10.1007/s11157-021-09589-7

REVIEW PAPER

***Ex-situ* biological CO_2 methanation using trickle bed reactor: review and recent advances**

Michal Sposob · Radziah Wahid · Keno Fischer

Doctoral Defense – Simona Dzurendova

On 23rd of April 2021, Simona Dzurendova successfully defended her thesis with the title *Sustainable Fungal Biorefineries: Optimizing production of valuable metabolites in oleaginous Mucoromycota*. The work was conducted at NMBU, under the supervision of assoc. prof. Volha Shapaval and co-supervision of Dr. Boris Zimmermann, prof. Achim Kohler and prof. Svein Jarle Horn.

Simona presented a trial lecture on the topic *Different methods for the production of biofuels and biochemicals from lignocellulosic biomass*. The main objective of the PhD research work was to investigate growth conditions that could improve the production of valuable metabolites in fungal biorefineries based on Mucoromycota fungi. The PhD work resulted in six publications and after an interesting and comprehensive discussion with the opponents, the committee concluded the PhD defense approved.

Mid-Term Evaluation of the Bio4Fuels FME Centre

The Bio4Fuels Centre, together with all the FME Centre's', had an extensive formal evaluation of its first 4+ years of operation in 2021. The Research Council of Norway appointed an international evaluation panel of two generalist and two expert evaluators:

Evaluator	Generalist / Expert
Mary J. O'Kane, Chair of the Independent Planning Commission of New South Wales, AUS	Generalist
Mattias Lundberg, Swedish Foundation for Strategic Research, SE	Generalist
Anne S. Meyer, Professor, Dept. of Biotechnology and Biomedicine, DTU, DK	Expert
Lars Waldheim, Waldheim Consulting, SE	Expert

The evaluation material was produced by Bio4Fuels Management during the fall 2020 and the (virtual) meeting with the evaluation panel was held on 23 February 2021.

Meeting agenda:

- **Part 1**: Introduction and evaluation session (session led by the scientific experts)
- **Part 2:** Meeting with PhD students (session led by the generalists/panel leader)
- **Part 3:** Evaluation session (session led by the generalists/panel leader)

An important part of the evaluation was the experience and feedback from the students involved in the Centre (part 2 no) for which representatives from Bio4Fuels management or supervisors were not present. In part 1 and 3 both management and representatives from research and stakeholders were present.

The results of the formal evaluation was an extensive report, providing detail review of the activities, together with a set of 13 recommendations – proposals to improve specific aspects of the operation of the Bio4Fuels as well as recommendations to review the focus of some of the research areas. A high-level overview of the recommendations is given below as well as the status of the implementation during 2021 after the evaluation.

Communication
- ✓ Web Page
- ✓ Social media
- ✓ Updated communication plan
- • Public Engagement

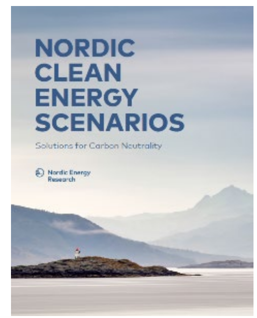
Stakeholder Engagement
- 👍 Prioritized Value chain Analysis
- 👍 Industry Exploitation and knowledge transfer
- • Industrial PhDs

Operations
- ✓ Capacity for Communication
- 👍 KPIs covering outputs
- 👍 Review of activities for final period
- 👍 Better promotion and analysis of Spin-in/spin-off projects

Students Engagement
- ✓ Student representation and Involvement in Management
- 👍 Improve PhD training at the Centre level

One of the more important changes has been to ensure greater involvement of PhD students and post docs in aspects of relevance to them – through having a PhD student in the Management group. A concrete result of this was re-establishing the pre-meeting for young researchers ahead of *Bio4Fuels Days 2021 and* making this an annual happening.

The evaluation of FME Bio4Fuels has been valuable to the Centre, pinpointing important improvement areas. Most important, however, was the confirmation that the research performed in Bio4Fuels is solid and relevant, and we are pleased that the Norwegian Research Council will fund the Centre for its final three years (2022 – 2024).



Report from Nordic Energy Research

The cooperation and interaction with Nordic Energy Research continues via Torjus Bolkesjø (WP3.1, NMBU) and his contribution to the report Nordic Clean Energy Scenarios. The report focusses on the Nordic vision and five different ways to a carbon neutral future.

IEA-Bioenergy (Task 39) report: Biofuels Policies and Market in Norway

IEA Bioenergy
Technology Collaboration Programme

University-, government- and industry-partners in FME-Bio4Fuels produced in 2021 a large report to IEA Bioenergy on Biofuels Policies and Market in Norway. The report was published in IEA Bioenergy Newsletter December 2021.

- Driven by the national climate policy, Norway introduced biofuel blend-in mandates for road transport in 2009. The blend-in rates started low and increased year by year. The mandate for biodiesel was 24.5% in 2021, aiming for 40% in 2030. The blend-in obligation for bioethanol into gasoline has been 4% since 2017. Mandatory blend-in of 0.5% biofuel in jet fuel was in in 2018 (first worldwide).
- The National Climate Plan 2021-2030, approved by the Norwegian Parliament April 14, 2021, prolongs the blend-in mandate as the primary tool for biofuels. The mandate will be expanded to include the construction industry and shipping fuel markets.
- The biofuel suppliers benefit from no carbon tax as a financial incentive.
- There is a growing commercial interest for utilizing forest residues as feedstock for biofuel production in Norway. Two plants are in progress for pilot stage.
- The suppliers must document the sustainability of their biofuel. For example, when using forest biomass as feedstock, at least 30% of the residues must be left in the forest.

- The sustainability of biofuels must be documented. I e, when using Norwegian forest biomass as feedstock, at least 30 % of the residues must be left in the forest.
- Norway currently has 40 biogas plants for processing municipal, food and industrial organic waste to fuel. Of these, 10 plants produce biogas for transportation.
- The world's largest liquefied biogas plant, Biokraft, is in Trøndelag. It processes fish farming and paper mill waste to biofuel. Other feedstocks are being evaluated.
- The largest Norwegian energy company Statkraft opened in November 2021 its test plant for producing forest-based biodiesel crude (Silva Green Fuel).

Figure 3: Location of biofuel plants in Norway 2021 (Biogas: largest plants only)

The main driver for the national biofuel policy is to reduce GHG emissions. Another driver is to reduce the export of low-quality forest biomass and thereby increase the national value creation.

SP Leader Meetings 2021

The Centre's sub-project leaders have the responsibility to follow up the WP leaders in their SP with regards to research progress, reporting and workplans. Management has met with the SP leaders nine times during 2021 (virtual due to geography and Covid-19). This has considerably improved the information flow in the Centre, as well as the management of it.

External workshops, seminars, and webinars in 2021

Date	Title
10 Mar	Webinar: Integrating the Gasification Value Chain in Bio4Fuels into an Industry
14 Apr	Co-Processing as route to deployment of advanced biofuels production
20 Apr	Biomass liquefaction Online Webinar

Centre Status Meetings 2021

The former "Cluster meetings" (for researchers and management) were expanded in 2020, and now include stakeholders. The meeting series has been renamed "Centre Status Meetings", of which there were four in 2020 (including Bio4Fuels Days). Due to Covid-19 the meetings have been virtual, which unfortunately lowers the degree of free discussions.

Date	Program

24 Mar	• Introduction, Centre Leader Duncan Akporiaye
	• Stakeholder Presentation: Biokraft AS, Håvard Wollan
	• IEA Task 39 Norway's Country Report, Odd Jarle Skjelhaugen, NMBU
	• PhD Project Presentation, WP3.3: *Utilization of lignocellulose hydrolysates as a source of carbon for production of microbial lipids by oleaginous fungi fermentation*, Simona Dzurendova, NMBU
	• Information from Bio4Fuels Management
	• Presentation of three associated EU Projects
	  ○ Waste2Road
	  ○ BL2F
	  ○ Baltic Biomass4Value
	• Nature Sustainability (2021): The land–energy–water nexus of global bioenergy potentials from abandoned cropland, Francesco Cherubini, NTNU

16 Jun	• IEA Net Zero by 2050, Centre Leader Duncan Akporiaye • Klimaplan 2021 - 2030, Mats Nordum, Norwegian Environment Agency • New PhD Project, WP3.3: Developing consolidated bioprocessing of lignocellulose materials, Cristian Bolano Losada, NMBU • The EU Project PyroCO2, Alexander Wentzel, Sintef • Presentation of Hyperthermics - a Bio4Fuels Stakeholder, Harald Nordal, Bio Strategist, Hyperthermics • Bio4Fuels Mid-way Evaluation - Results and Actions, Centre Leader Duncan Akporiaye • Highlights from Bio4Fuels Sub Project 2 (SP2), Kai Toven, RISE-Pfi • Presentation of a New and Relevant SFI: *Smart Forest*, Rasmus Astrup, WP1.1, NIBIO • Presentation of a New and Relevant SFI: *Industrial Biotechnology*, Svein Jarle Horn, Deputy Centre Leader, NMBU • Numerical and experimental investigations of liquid biofuels under CI conditions, Michal Lewandowski, Post Doc in WP5.3, NTNU
8 Sep	• Welcome and information from Management, Centre Leader Duncan Akporiaye • Challenges in securing the public support - and sustainability - of biofuels, Søren Løkke, Aalborg University • Bio4Fuels PhD Project: Conversion of synthesis gas from biomass gasification over cobalt catalysts, Oscar Luis Ivanez Encinas, WP4.2, NTNU • Status Bio4Fuels' Mid-Term Evaluation, Centre Leader Duncan Akporiaye • SP1 Workplans 2021-2024, Francesco Cherubini, Leader SP1, NTNU • SP2 Workplans 2021 - 2024, Judit Sandquist, Leader SP2, Sintef • SP3 Workplans 2021 - 2024, Aniko Varnai, Leader SP3, NMBU • SP4 Workplans 2021 - 2024, Morten Seljeskog, Leader SP4, Sintef • SP5 Workplans 2021 - 2024, Bernd Wittgens, Leader SP5, Sintef
18 Nov	Bio4Fuels Days 2021 (see next page)

Bio4Fuels Days 2021 (16 -18 November)

16 November

Pre-meeting for PhD students and post docs (Quality Hotel River Station, Drammen)

- Introduction
- Get to know each other - Short presentations
- Discussion - Biofuels in society today (see below). Chair: Svein Horn, NMBU
- Presentation techniques, a talk by Stein Mortensholm from SINTEF
- Mount posters
- Dinner for PhD students and post docs

Topic for the discussion session:

"There are controversies around biofuel in the society today. How do you feel about that? If you were to convince someone outside your field about biofuels' role in the green conversion, how would you do that?"

Young researchers' discussions. Photo: Janne Beate Utåker

17 November

Open, International Meeting (Quality Hotel River Station, Drammen)

Site visit to Silva Green Fuel's Demonstration Plant

- Bus to Tofte, Hurum
- Site visit with lunch
- Bus to Hotel River Station, Drammen

Visiting Silva Green Fuel's Demonstration Plant at Tofte, Norway. Photos: Janne B Utåker and Bente Paulson

Digital Session (Teams)

- **Welcome** – Duncan Akporiaye
- **The role of biofuels in the IEA's Net Zero by 2050**, Praveen Bains, IEA
- **Communicating Sustainability – challenges and opportunities,** Zoe Harris, University of Surrey

- **Commercial roll out of pyrolysis technology in Europe**, Gerhard Muggen, BTL
- **Working towards a mass balance standard for co-processing pyrolysis oil**, Charlotte Koppen and Ortwin Costenoble, NEN
- **Challenges with Aviation Fuels**, Arvid Løken, Avinor

Poster Session with Refreshments

Photos: Janne Beate Utåker

Thursday 18 November

Bio4Fuels Partners' Meeting (Physical)

Introduction by Svein Horn, Deputy Centre leader

SP1

- *Brazilian sugarcane industry: current status, future trends and sustainability*, by Marcos Djun Barbosa Watanabe, NTNU
- *The future role of forest-based biofuels: Industrial impacts in the Nordic countries*, by Eirik Ogner Jåstad, NMBU

SP2

- *Update from ETIP BioenergyIndustrial,* Judit Sandquist, SINTEF
- *Update on HTL experiments in 2021 – the effect of bark content and temperature*, Judit Sandquist, SINTEF

SP3

- *Organosolv pretreatment: accessibility of cellulose, lignin precipitation on fibers and morphology*, Prajin Joseph and Mihaela Tanase-Opedal, RISE Pfi

SP4

- *Biomass gasification in a bubbling fluidized bed gasifier: a comparison between wood and grass pellets gasification,* Ramesh Timsina, USN

SP5

- *CPU efficient modelling of (energy) conversion processes with detailed chemistry - combustion, catalysts, biomass and more,* Lars Seidel, Logesoft (Teams)
- *Providing compound models for biorefinery processes* Robert Pujan, NTNU

f3 - the Swedish Knowledge Centre for Renewable Transportation Fuels, Ingrid Nohlgren, Chalmers Industriteknik (Teams)

Discussions - Work Plans 2022-2024 Part One (Groups)
Group 1: SP1 and Relevant Industry + representatives from SP2, SP3&SP4
Group 2: SP5 and Relevant Industry + representatives from SP2, SP3&SP4
Plenum Session: Presentation of Group Work Part One

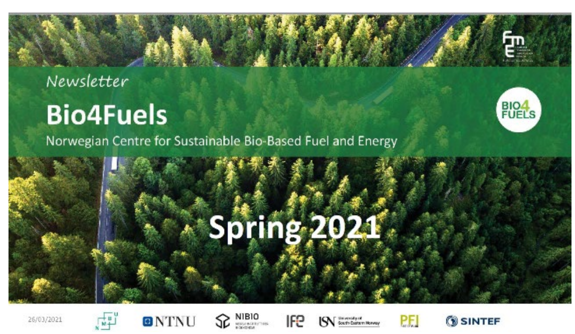
Discussion - Work Plans 2022-2024 Part Two (Groups)
Group 1: SP3 and Relevant Industry + representatives from SP1&SP5
Group 2: SP2 and Relevant Industry + representatives from SP1&SP5
Group 3: SP4 and Relevant Industry + representatives from SP1&SP5
Plenum Session: Presentation of Group Work Part Two

Summary and Closing, Svein Horn, Deputy Centre leader

Quality Hotel River Station, Drammen Photo: Choice Hotels AS

Bio4Fuels Newsletters

To improve the communication of the Centre's activities, newsletters have been sent out to the Bio4Fuels partners in the spring, summer, autumn and December of 2021. There is a person in Management dedicated to this work, contacting the research partners in person and collecting the latest within technology, publications, innovation, recruitment etc.

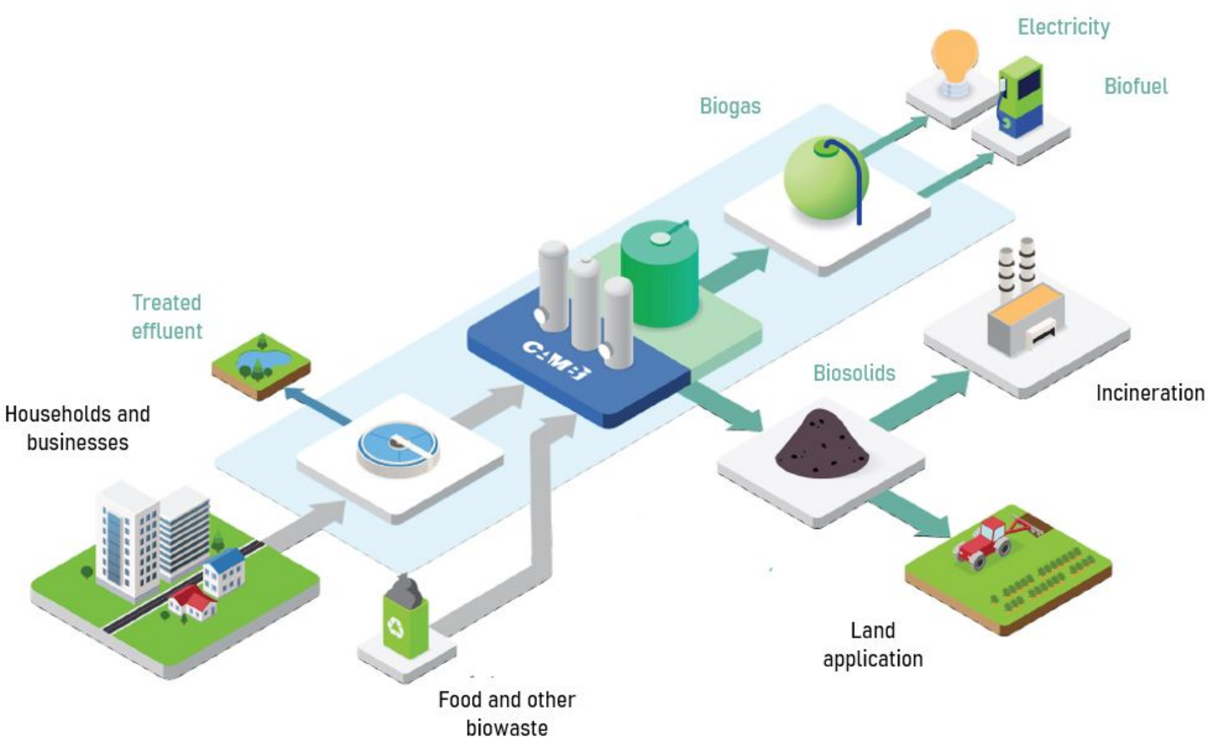


BIO4FUELS INDUSTRIAL STAKEHOLDERS' INSIGHTS

Cambi is an innovative solutions provider for wastewater sludge and organics treatment. Cambi's core technology, the **thermal hydrolysis process (THP)**, is used with anaerobic digestion at medium and large wastewater treatment plants to achieve multiple cost-saving and environmental benefits.

A primary benefit is increased biogas production. Thermal hydrolysis enhances biogas production by improving the destruction of the cell walls of microorganisms within sludge, causing higher volatile solids reduction. Methane is therefore extracted in greater amounts during anaerobic digestion. The same volume of sludge, pre-treated via thermal hydrolysis, can yield up to 40% more biogas than conventional digestion.

Besides the benefit of increased renewable energy from sludge, the final biosolids produced with THP is significantly reduced in volume and free from the regrowth of pathogens. The technology improves digester efficiency, lessens capital investments for new digestion plants, and makes biosolids management strategies more flexible, mitigating several operational risks for many clients.



The company started in Norway in the 1990s and is now an international force, having sold over 75 THP systems worldwide that service about 110 million people across 24 countries as of 2022.

In Norway, Cambi technology is used in several plants, one of which - the Oslo Romerike Biogas Plant – specifically treats household separated food waste and industrial biowaste (several other Cambi plants co-digest this material with sludge). The plant upgrades the methane produced to liquefied biogas fuel. It is then used to run over 130 public commuter buses in Oslo. As a result, carbon dioxide emissions are reduced by approximately 10,000 tonnes each year, and local air quality is improved due to lower particulate emissions.

Some plants with Cambi technology have surplus electricity or biomethane and sell this excess energy to their local power or natural gas grids. An example is the Basingstoke Sewage Treatment Works in the United Kingdom, an energy-positive sludge treatment centre that creates up to 62 MWh of electricity from biogas every day.

Cambi has had significant collaborations with the Norwegian University of Life Sciences (NMBU) and the Bio4Fuels program over the last two decades.

RESEARCH CENTRE ESTABLISHMENTS

Before the Bio4Fuels program began, Cambi had carried out research together with different partners for a long time and was among a handful of industry partners for the establishment of CenBio or the Bioenergy Innovation Centre in 2009. Headquartered at the Ås campus of NMBU, the centre championed collaborative work and research among various biomass and bioenergy companies, groups, and academic institutions. Under the centre's work and existence for seven years, the previously fragmented bioenergy industry became unified and strengthened in its goal of increasing biomass energy use in Norway.

The Bio4Fuels program then kicked off in 2017, establishing the Norwegian Centre for Sustainable Bio-based Fuels and Energy. Cambi serves as a member of the Technology subgroup of program partners and has supported the program financially and in-kind every year since.

STUDIES ON BIOGAS, SLUDGE DIGESTION, AND THP

In the same year CenBio was established, Cambi supported the project "From biomass to biogas" with NMBU and Bioforsk. The project aimed to research the conversion of various substrates (biomass and co-products from food production) into biogas using thermal pre-treatment, namely Cambi's thermal hydrolysis process, among other pre-treatment methods. Cambi provided the use of its THP set-up at Ås and invested in new equipment for the tests conducted, along with in-kind support.

In 2016, Cambi partnered with NMBU and the Research Council of Norway to assist in a PhD study on digested sludge (digestate) dewatering. The study's goal is to provide recommendations for the optimisation of digestate dewatering and to note the impacts of the thermal hydrolysis process on digestate dewatering.

Another recent study of note Cambi is aiding focuses on new generation biofertilisers. The study, done in partnership with China's Biogas Research Institute, among others, aims to suggest methods on how to secure the use of various digestates as fertilisers while studying how to reduce nitrous oxide emissions in the process. Digested sludge from specific Cambi plants is used in the study, with results expected in 2022.

Cambi has also worked extensively with Bio4Fuels collaborators, namely the Norwegian Institute of Science and Technology (NTNU), SINTEF, and the Norwegian Institute of Bioeconomy Research (NIBIO). Cambi's partnerships within and support for this extensive network of institutions move forward its vision of securing greater understanding and the strengthening of the biogas market in Norway and around the world.

btg-btl biomass-to-liquid

From Sawdust to Tank

The Swedish joint venture Pyrocell, consisting of the wood industry company Setra and the oil company Preem, will be utilising BTG Bioliquids technology. Construction of the pyrolysis facility has started in 2020 and production in September 2021.

The production plant is built on the company grounds right next to the Kastet sawmill of Setra in Gävle, about 170 kilometers north of Stockholm.

Photo: BTG/Pyrocell

The necessary raw material in the form of sawdust is already available eliminating the need for further transport. The oil produced is then processed in Preems refinery in Lysekil, on the Swedish west coast. The plant will convert roughly 35,000 – 40,000 tons of dry wood residues into oil each year. With this produced pyrolysis petrol an equivalent of 15,000 family cars can be powered per year. The biofuel is mixed with other types of fuel – biofuels as well as fossil fuels – resulting in a petrol and diesel that is partly composed of sustainable oil. This ensures that it will comply with the European RED II directive under which, starting in 2020, petrol must contain a certain fraction of renewable energy from sustainable sources such as wind, sun, and biomass.

Silva Green Fuel

Hydrothermal Liquefaction (HTL) Demonstration Plant

Silva Green Fuel's plant at Tofte, Norway is now running and soon finished.

- Feedline: All instrumentation connected to biomass processing are installed, tested and in operation
- HTL core system: The HTL high-pressure system, including reactors, heat exchangers and accessories, are installed and tested
- Downstream systems: Equipment for oil separation and chemical recycling are installed and tested.
- The remaining equipment, including process gas treatment and laboratory facilities, were installed in parallel with the above mentioned systems

Silva Green Fuel's plant was mechanically completed in the summer 2021, and the whole plant was finished in November 2021.

Photos: Ingo Machenbach, Silva Green Fuel

Norges Skogeierforbund

The Norwegian Forest Owners' Federation

The role of forests in the Norwegian climate plan

At the beginning of 2021 the government presented its plan to achieve the climate goals by 2030 ("*Meld. St. 13 Klimaplan 2021-2030*"). The plan implies a clear recognition of the forest's role in the climate context, which involves sequestration and storage of carbon in forests, substitution of fossil products with wood-based products and extended storage of carbon in buildings and other long lived forest products.

The government will continue existing climate measures in forests, such as fertilization, denser planting and breeding of forest plants. They will also consider new measures, such as tending of young stands and preventing damage from root fungus. Today, the carbon sequestration in the Norwegian forest is decreasing due to the age structure. The measures could have a high effect in the long term and can contribute to securing a large carbon storage in Norwegian forest for the following generations. Combined, the measures can increase the yearly sequestration in the Norwegian forests with 6,5-8 mill. tons CO_2 in 2100.

Products from forests, such as biofuels substituting fossil fuels, can help decrease the emissions. Stimulating the use of biofuels has been a part of the Norwegian policy for several years already, and the government plans to continue with this measure by making it mandatory to sell a certain proportion of biofuels both for road traffic, shipping and heavy machinery.

The government also points out that using timber in constructions has a positive climate effect. Measures that stimulate to increased use and reuse of timber and wood products in buildings and constructions therefore is climate friendly. The state builds a lot of public buildings and constructions, and they plan to create a strategy for the use of climate requirements in public procurement. They will also work on bringing climate requirements into technical criteria for buildings.

Photo: Tenk Tre

Brazilian sugarcane ethanol is cost competitive with patrol and reduces climate gas emissions by 80%

Meeting the global climate challenges, UMOE Bioenergy has been a large biofuel producer in Brazil since 2009. This renewable biofuel is

The Brazilian bioethanol production company 'Foundation of the Paranapanema Distillery' was established 1980. The company was acquired by UMOE in 2009 and was, after substantial investments, renamed Umoe Bioenergy (UBE). In 2021 UBE reported a profit after tax of 150 million NOK.

UBE grow and harvest sugar cane in the State of Sao Paulo in Brazil and produce large volumes of sustainable bioethanol and electricity. The soil in this area is among the highest productive in the world. UBE grow the sugar cane on 40,000 hectares leased arable land and process it in its own state-of-the art mill.

Alcoholic fermentation is a complex biochemical process during which yeasts convert sugars to ethanol, carbon dioxide and other metabolic byproducts. The process is being operated by skilled staff, helped by advanced sensor technology. The biofuel is being mixed with fossil gasoline or used as a stand-alone low-carbon fuel. Bioethanol powers 70 % of Brazilian cars.

The annual production is 170.000 m^3 ethanol and 151 GWh electricity. 2.5 million tons crushed sugarcane is needed to produce this energy volume, and about 900.000 seedlings are being planted every year. The staff makes1.300 people, and the turnover is about 2.5 billion NOK.

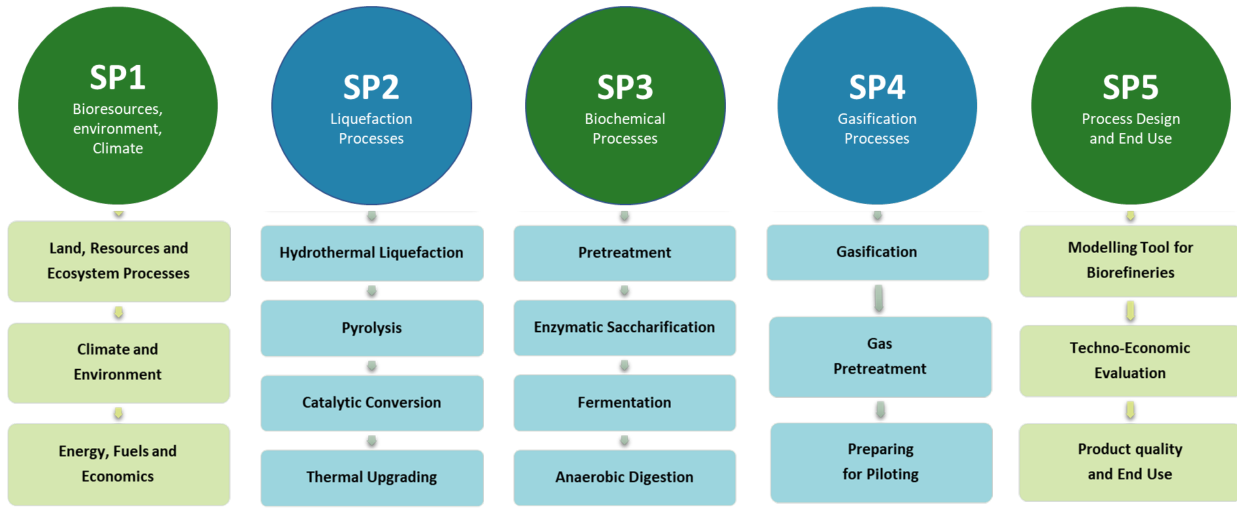
UBE also has income from the sale of CBios, or quotas paid for the reduced fossil CO2 emissions.

UMOE Bioenergy Plant in Brazil Photo: UMOE

The biofuel is being produced about 2.000 km from the Amazon. The production occupies less than 1% of arable land in Brazil and is not competing with the national food production.

Highlights from Bio4Fuels' Work Packages

As shown below, the high-level value chain (SP (sub project)) establishes interaction across focussed research activities (work packages (WP)), addressing the five challenges of bioresources (SP1), Liquefaction Processes (SP2), Biochemical Conversion (SP3), Gasification Processes (SP4) and End use (SP5).
Within this organisational structure, Bio4Fuels has focus on and coordinates the activities along the value chains, addressing specific challenges and bottlenecks needed to go from resources to products using the most relevant technological approaches for biofuels production.



Bio4Fuels – WP highlights in 2021

SP1: Bio-resource, Environment and Climate
- Resource use and availability in Norway. - Climate change impacts and mitigation - Economic policies for sustainable biofuel economy
SP Leader: Francesco Cherubini

WP1.1	Land, Resources and Ecosystem Processes (Rasmus Astrup, NIBIO)
WP1.2	Climate and Environment (Francesco Cherubini, NTNU)
WP1.3	Energy, Fuels and Economics (Torjus Bolkesjø, NMBU)

Background and approaches

This subproject addresses sustainability aspects related to bio-resources with a particular focus to the Norwegian context. Research activities in this domain include the availability and options for procurement of bio-based resources under different management strategies, modeling biomass-to-biofuels value chains and their climate change mitigation potential, environmental impacts and socio-economic implications.

State-of-the-art modelling tools are applied to simulate forest state and structure and cost-supply curves of wood resources. Value chains of biofuel options are compiled and assessed under a life-cycle perspective, and climate change mitigation potentials of their large-scale deployment explored. Their contributions to multiple sustainability indicators are quantified, as well as market dynamics and impacts on welfare. The analysis includes current and near-term economic measures and policies governing the many aspects of Scandinavian biofuel economy with the view to outlining potential sound economic policies to enable a sustainable biofuel economy in Norway and Scandinavia.

The research results are expected to provide useful information to industries and public authorities about the best ways to manage biomass feedstocks, biofuel production technologies, and biofuel applications under the dual goal of renewable energy supply and climate change mitigation. In the remaining lifetime of the center, we will develop a sustainability assessment framework and apply it to the novel technologies emerged in Bio4Fuels. The analysis will show the main opportunities and barriers, dependency on national and imported biomass feedstocks, and potential co-benefits and trade-offs with other SDGs (integration of environmental, social and economic indicators).

2021 SP1 Bioresources, Environment and Climate:
The research activities in 2021 have improved our assessment framework for analysis of biofuel systems in Norway by developing novel approaches that consistently integrate climate forcing agents through the value chain, from resource supply to logistics, biomass conversion to biofuels and final use. We have also performed case-studies specific to quantify the climate change mitigation potential of biofuel options in Norway. Analysis includes articles (currently under revision) on the additional climate change mitigation benefits of biofuels for road transport in Norway under increasing rates of electrification of the fleet and on the production of advanced biofuels for the shipping sector.

WP1.1 Land, Resources and Ecosystem Processes - Rasmus Astrup

The activities in WP1.1 will in the future be linked with the activities of SmartForest with the aim of developing the digitally enabled sustainable feedstock supply chains based on Norwegian forests.

In 2021, WP1.1 has focused on developing approaches for how to best develop forest feedstock supply for new biofuels plants in Norway. Forest-based feedstock supply for biofuels must be evaluated in conjunction with the other products developed from forest harvesting (e.g. sawlogs and pulp wood). Sustainability criteria for biofuels production are increasingly clear in the demand for a primary focus on byproducts or side streams from existing harvest rather than harvesting additional forests for the sake of biofuels production.

In 2021, WP 1.1 started a close collaboration with Biozin to investigate different feedstock baskets (different mixes of woody biomass fractions) potentially can supply the first planned Biozin plant. The study includes exploration of how different supply strategies will influence cost (feedstock and logistic) and expected climate benefits. The study is to be completed in 2022.

WP1.2 Bio-Resources, Environment, Climate - Francesco Cherubini

Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy

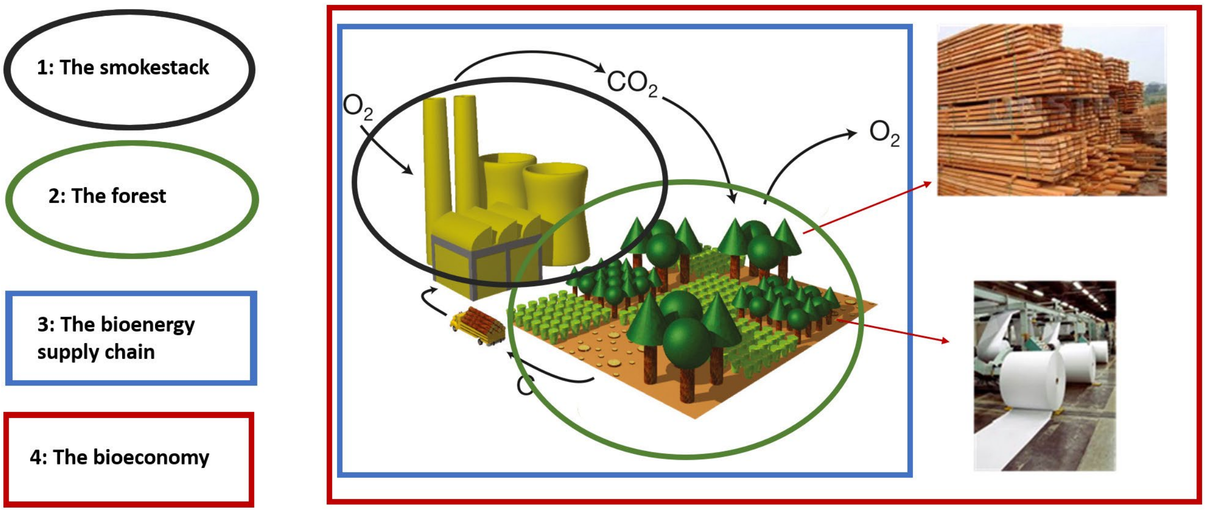
From time to time, scientific articles and statements in the media have raised concerns over the climate effects of bioenergy from managed forests. As some of these statements seem to reflect misconceptions about forest bioenergy, a scientific article entitled "*Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy*" has been produced within the framework of IEA Bioenergy Task 45 with the aim to clarify some basic concepts.

The contrasting findings about the climate effects of forest bioenergy are due to the wide diversity of bioenergy systems, local contexts, and assessment methods. Studies showing that climate effects of forest bioenergy are worse than fossil fuels typically focus on narrow perspectives (see Figure) based on carbon balances of individual forest stands and/or comparing emissions at the point of combustion. Payback time calculations (e.g., carbon debt) are influenced by subjective methodology choices and do not reflect the contribution of bioenergy within a portfolio of mitigation measures, so it is neither possible nor appropriate to declare a generic value for the maximum acceptable payback time for specific forest bioenergy options.

These simplified approaches neglect system-level interactions that influence the climate effects of forest bioenergy. Holistic assessments show that forests managed according to sustainable forest management practices can contribute to climate change mitigation by providing bioenergy and other forest products that replace GHG-intensive materials and fossil fuels, by strengthening forest sinks, and carbon storage in long-lived forest products. Demand for forest bioenergy can drive expansion of forest areas into marginal or fallow land, so to additionally increase terrestrial carbon stocks.

There is a need for a systems approach in assessing options and developing policy for forest bioenergy that: (1) considers the whole life cycle of bioenergy systems, including effects of the associated forest management and harvesting on landscape carbon balances; (2) identifies how forest bioenergy can best be deployed to support energy system transformation required to achieve climate goals; and (3) incentivizes forest bioenergy systems that augment the mitigation value of the forest sector as a whole. Limited perspectives can lead to decisions that make medium- to long-term climate goals more difficult to achieve.

The most important climate change mitigation measure is the transformation of energy, industry and transport systems so that fossil carbon remains underground. Narrow perspectives obscure the significant role that bioenergy can play by displacing fossil fuels now, and supporting energy system transition.



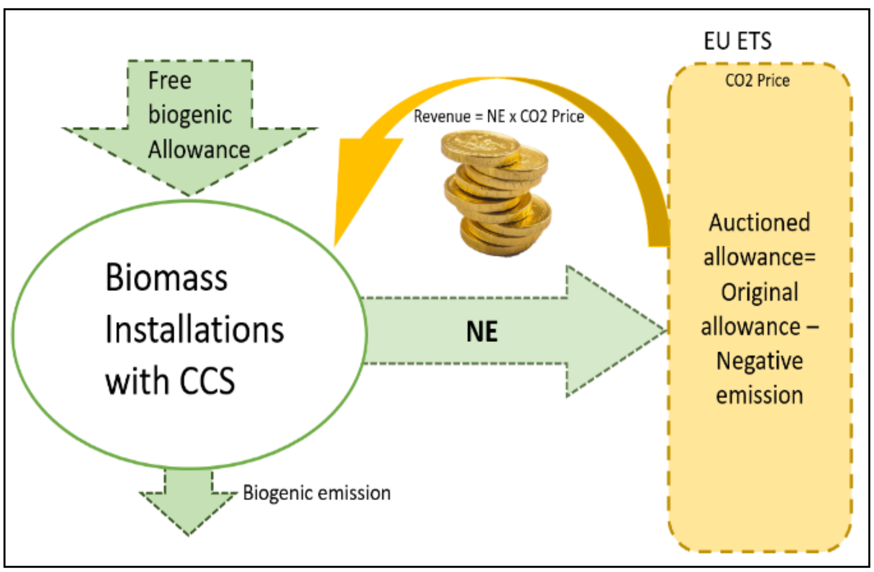
Analysis of climate change mitigation aspects of forest-based bioenergy have been affected by inconsistent system boundaries: Option 1 (black) considers only the stack emissions; Option 2 (green) considers only the forest carbon stock; Option 3 (blue) considers the bioenergy supply chain; Option 4 (red) covers the whole bioeconomy, including wood products in addition to biomass. The more narrow the perspective an analysis considers, the smaller the climate change mitigation benefits of forest-based bioenergy appears in comparison to fossil energy. A large system perspective is needed to account for the benefits of bioenergy in the context of a wider bioeconomy.

Full publication details:
Cowie, A., G. Berndes, N. Bentsen, M. Brandão, F. Cherubini, G. Egnell, B. George, L. Gustavsson, M. Hanewinkel, Z. Harris, F. Johnsson, H. Junginger, K. Kline, K. Koponen, J. Koppejan, F. Kraxner, P. Lamers, S. Majer, E. Marland, G. Nabuurs, L. Pelkmans, R. Sathre, M. Schaub, C. Smith, S. Soimakallio, F. Van Der Hilst, J. Woods and F. Ximenes (2021) Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy. *GCB Bioenergy* 13: 1210-1231. Available at: https://doi.org/10.1111/gcbb.12844.

Link:
IEA Bioenergy Task 45: Climate and Sustainability Effects of Bioenergy within the broader Bioeconomy:
https://task45.ieabioenergy.com/

WP1.3 Energy, Fuels and Economics - Torjus Bolkesjø

Our research in 2021 included a study developing a pathway toward a fossil-free Nordic Road transport in 2050 based on electrification and wood-based biofuels. The study shows that, from a resource viewpoint, a 100% fossil-free Nordic transportation sector based on a combination of these two options is feasible, but it will require a massive build-out of renewable electricity capacity and increased utilization of wood resources in the coming decades. Despite an expected increase in wood demand from pulping industries, it seems likely that the Nordic Forest sector can deliver the demanded amounts of biomass for biofuels while at the same time keeping harvest levels below annual forest growth. However, the transition will come with some major implications to the forest sector value chain. First, the simultaneous increase in demand from pulping industries and biofuel will cause an overall increase in wood use (pulpwood, chips and sawdust) consumption of approximately 40 mill m3, of which the biofuels share is approximately 20–25% in our base-scenario (the current Nordic harvest level is approximately 160 mill m3). Second, the tall oil produced in pine-based pulp mills is almost exclusively used for biofuels. Third, the utilization of harvest residues will increase more than 300% compared to the current level, since biofuel production reallocates some of the current raw material used in bio-heating. WP1.3 researchers also contributed to the Nordic Clean Energy Scenarios (NCES) report published by Nordic Energy Research. The report lays out three main scenarios for carbon neutrality in the Nordic region by 2050. Electrification is the main solutions for decarbonization, but substantial contributions from bioenergy, power-to-X, CCS and behavioral change is needed to, according to the report. For bioenergy, the NCES report foresees a larger shar of the biomass directed to biofuels.



SP2: Liquefaction Processes
- Develop novel technologies for direct conversion of lignocellulosic feedstocks to transport biofuels – through pyrolysis and hydrothermal liquefaction - Increase the robustness of the liquefaction and catalytic processes throughout the whole value chain. - Increase the energy efficiency through the whole value chain
SP Leader: Judit Sandquist

WP2.1	Pyrolysis (Kai Toven, RISE PFI)
WP2.2	Hydrothermal Liquefaction (Judit Sandquist, SINTEF ER)
WP2.3	Thermochemical Upgrading (Roman Tschentscher, SINTEF Industry)
WP2.4	Chemo-catalytic conversion (De Chen, NTNU)

Background and approaches

The liquefaction value chain focusses on one of the major routes for the conversion of solid biomass to biofuels and related products. The conversion processes involve high temperature treatments that aim to achieve the desired composition of the biofuel. The major challenge is to achieve this in as few processing steps as possible, minimising the overall costs.

This subproject includes two technologies, pyrolysis and hydrothermal liquefaction for biomass conversion to intermediates and two catalytic technologies, one to upgrade the bio-oils to transportation-quality biofuels and a chemo-catalytic conversion to valuable chemical- Ethylene glycol and Propylene glycol production. The sub-project uses mainly experimental approaches.

With regards to pyrolysis, biomass conversion by pyrolysis combined by anaerobic digestion to increase the overall energy efficiency of the process is investigated. In addition, a two-step pyrolysis process, pyrolysis with direct vapour upgrading to produce a higher quality suitable as drop-in fuel for marine or aviation fuel blends is being developed. The HTL work package focuses on the development of a more robust and feedstock flexible technology by understanding and controlling the inorganics during the process through experiments and modelling. In addition, operational challenges such as feeding depressurization and the influence of the feedstock properties are investigated in a continuous mini pilot.

The catalytic processes are focusing on increased simplicity and stability of the catalysts. For upgrading, development of a simple and robust catalytic bio-oil/biocrude upgrading process as well as fractionation and detailed analysis of the different streams are carried out. The main focus of the chemo-catalytic conversion is enhancing the catalyst stability of the copper catalyst. In addition, electrochemical conversion is studied.

The TRL range of the SP is 3-5.

2021 SP2 Liquefaction Processes: In *Pyrolysis* (WP2.1), 2 stage catalytic pyrolysis experiments are conducted with a representative bio-oil product. The experimental results show that that by combining pyrolysis and anaerobic digestion, higher product yields on carbon basis can be obtained as compared to a pyrolysis process alone (no biomethane). In *HTL* (WP2.2) the first experiments are performed in the continuous mini-pilot. Due to operational issues, only the batch experiments could be fully performed, and a paper was written based on the results. *Upgrading* (WP2.3) is investigation a process where the hydrogen donor solvent can be fully regenerated using a hydrogen pressure in the catalytic HDO reaction. The reaction is capable to reduce the oil content of bio-oils from 5-10% to below 1% using cheap catalysts. In *Catalytic conversion* (WP2.4) a mini pilot is operative producing a pyrolysis bio-oil with a very low (<10%) oxygen content and a new PhD student has started.

The stakeholder involvement is good in all WPs. The SP is generally on track with only slight delays.

Achievements

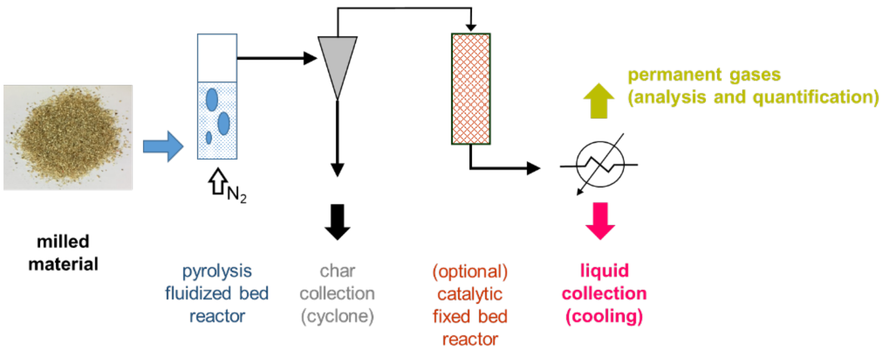
- Tools developed for testing two-step catalytic fast pyrolysis in both micro and bench scale
- Paper submitted discussing the results of the HTL experiments with bark addition.
- Simpler and cheaper catalytic HDO process compared to state-of-the-art demonstrated
- Catalyst for converting small-to-long chain hydrocarbons with oxygen remove is demonstrated in continuous lab reactor.
- Catalytic upgrading of bio liquids focused on studying the effects of variations in operation conditions
- Lab scale infrastructure for batch and continuous conversion was established for electrochemical conversion
- The SP has several coupled EU projects, where the research is undertaken jointly

WP2.1 Pyrolysis - Kai Toven

Pyrolysis processes are of particular interest for direct conversion of biomass and residue feedstocks into liquid biofuels, biochemicals and biocarbon materials. In Bio4Fuels, the research team at RISE PFI are addressing with two novel conversion routes for cost efficient production of biobased transportation fuel based on pyrolysis technology. First, coproduction of biogas transportation fuel, biocrude and biocarbon is addressed by combining intermediate pyrolysis technology and anaerobic digestion. Second, a novel two-step catalytic fast pyrolysis process is addressed as a route for direct conversion of biomass and organic waste feedstocks into a low molecular biocrude suitable for further upgrading to a marine or aviation “drop in fuel”.

In 2021, the activity on developing a catalytic fast pyrolysis process for producing a marine or aviation drop in fuel started up. As compared to previous work on catalytic fast pyrolysis technology, the main strategy here is to develop a two-step catalytic process that allows using contaminated organic waste like waste wood and non-recyclable plastic waste as feedstocks. These feedstocks cannot be material recycled today and goes to direct combustion. Key innovations here are that catalyst deactivation due to deposit of inorganic contaminants from the feedstock on the catalyst can be avoided in two-step pyrolysis process and that the use of organic waste material as feedstocks will reduced carbon footprint and improved profitability of the process. In catalytic pyrolysis, the catalyst is reused after burning off coke formation so long catalyst lifetime is essential for the process.

RISE PFI has developed tools for testing two-step catalytic fast pyrolysis in both micro and bench scale. A principal diagram for the continuous bench scale reactor system in bench scale is shown below. Here, small particular wood material is fed to a fluidised bed reactor. After char removal, the pyrolysis vapours are led to a catalytic reactor filled with pelletised zeolite catalyst before liquid condensation. In 2021 the reactor system was set up for testing waste wood and the fluidisation was improved in the reactor to obtain more ideal fast pyrolysis conditions. By now initial tests have been carried out and a study on catalytic pyrolysis of waste wood is in progress.



a)

d)

b)

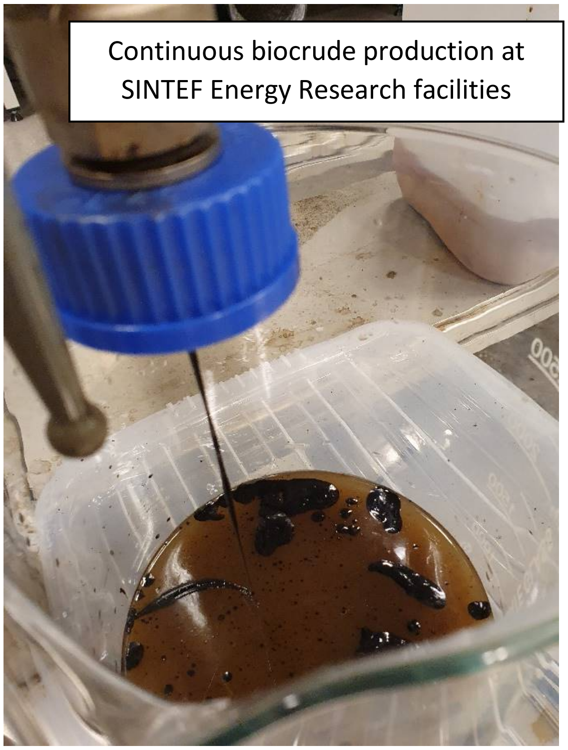
c)

Photo: *The Bio4Fuel research team at RISE PFI are exploring catalytic pyrolysis of waste wood for producing a biocrude quality suitable for upgrading in to a marine or aviation drop in fuel. a) Principal diagram for the continuous bench scale fast pyrolysis reactor system. b) Waste wood feedstock. c) Fresh and used zeolite catalyst pellets with coke. d) Low-viscous biocrude sample produced from waste wood.*

WP2.2 Hydrothermal Liquefaction - Judit Sandquist

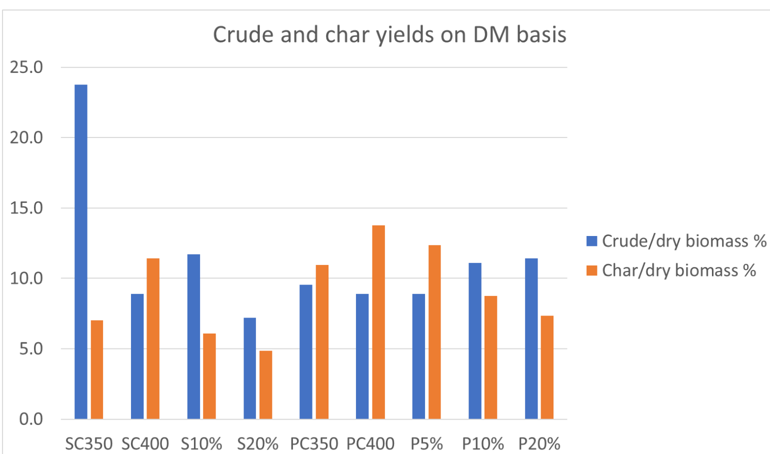
Hydrothermal liquefaction (HTL) is a thermochemical process that takes advantage of the water in the feedstock, at process conditions where the heat of evaporation for water is avoided. This makes the process very interesting for high moisture feedstock such as organic residues and sludges.

The technology uses high pressures and temperatures where the water is at sub- or supercritical state. At these conditions, the water alters its physical and chemical properties which result in chemical reactions that dissolve the organic structure of biogenic materials and convert them to fuel intermediates.



Continuous biocrude production at SINTEF Energy Research facilities

Through the Norwegian national infrastructure project, NorBioLab2, SINTEF Energy Research has invested in a continuous lab-scale HTL mini-pilot system, which is now operational, and the first experiments are conducted in 2020. The work in 2021 focused on developing the methodology for the experiments and examining available analysis possibilities. An experimental campaign was carried out studying the effect of temperature (subcritical vs. supercritical conditions) and the addition of bark on the oil quality. The experiments were carried out in the framework of summer research at SINTEF Energy Research and involved a student. Due to operational issues, not all continuous experiments could be performed. The products of the batch experiments were analyzed by TGA (simulated distillation of oil with a method developed for TGA by NREL), FTIR and the aqueous phase underwent TOC analysis. A paper describing the results of the batch experiments are submitted to ICONBM 2020 conference aiming a publication in Chemical Engineering Transactions (CET) in 2022. The results of the batch experiments indicate that the temperature is the main variable that alters both the yields and qualities of the products. Simulated distillation and FTIR analysis could not reveal that bark addition affected the biocrude quality, which is promising with regards to use of bark as a resource blended with wood chips up to 20 %. However, it affected the char densities as the picture shows.



In 2022 the focus of the HTL work package will be on experimental work, aiming to perform the continuous counterpart of the 2021 experiments.

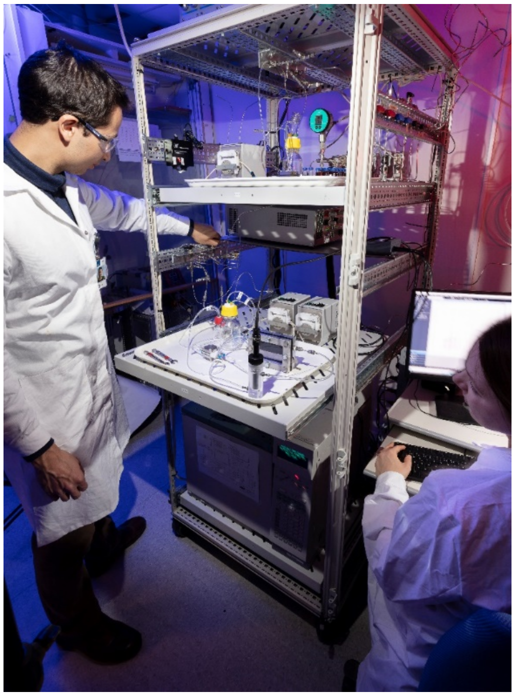
WP2.3 Thermochemical upgrading of bio-oils - Roman Tschentscher

During the year 2021 significant progress was achieved in several national and European projects related to Bio4Fuelsed, both in the field of catalytic and electrochemical bio liquid upgrading.

The NFR IndNor project catalytic upgrading of bio liquids focussed on studying the effects of variations in operation conditions. This work was performed by the exchange student Flavien Gilles from the École nationale supérieure des ingénieurs en arts chimiques et technologiques (INP-ENSIACET). Flavien screened the operational window using a high-pressure batch autoclave with respect to hydrotreatment temperature, hydrogen pressure and residence time at high temperature. Further the crude bio oil was fractionated by extraction and the obtained fractions were tested separately. To summarize, temperatures above 350 °C are required for significant oxygen removal. The hydrogen pressure can be significantly reduced to below 50 bar. Cracking of larger compounds to mono/dimers is not achieved in quantitative amounts. Based on this work SINTEF has been a partner in a Horizon-Europe proposal which was submitted in February 2022. Further, an oral presentation about the recent results will be given at EUBCE 2022.

Pyrolysis experiments within the EU-project BRISK II were conducted in collaboration with the University of Huddersfield, studying the effect of fluidization gas composition on the yield and composition of product fractions. The data are currently analysed with the aim of a joint publication.

In the field of electrochemical conversion of bio liquids lab scale infrastructure for batch and continuous conversion was established, which complements the pilot scale electrochemistry rig in Trondheim. The rigs contain online gas product analysis and automatic sampling for detailed offline analysis. The EEA-Norway Grants project NoViCo was established during spring 2021. Together with partners at Riga University of Technology and the Estonian University of Life Science we will develop novel combinations of biomass fractionation, electrochemical depolymerization and further valorisation to fuels and platform chemicals.



The Horizon 2020 project EBIO aims the electrochemical upgrading of crude bio liquids to simplify purification and downstream hydrotreatment. Target reactions are the electrochemical depolymerization of lignin-based polymers, reduction of sugar- and lignin-based aldehydes to stable alcohols and phenols and decarboxylation of organic acids. The recent results will be presented in three scientific presentations at EUBCE 2022. Further a free seminar, consisting of three keynote lectures on electrochemical conversion of bio liquids will be hold as part of EUBCE 2022.

WP2.4 Chemo-catalytic conversion – De Chen

Catalytic conversion of main intermediates of pyrolysis process to value added products such as ethylene glycol or propylene glycol could enhance the economics of the whole biomass to fuel process. Haldor Topsøe developed a new process to produce bio-based plastics from biomass. MOSAIK™ – is a solution for cracking of sugars to an intermediary product which can be further converted to monoethylene glycol (MEG) or other chemicals using Haldor Topsoe's patented processes and catalysts[1].

Copper based catalyst are good candidate for selective hydrogenation, however, suffer from poor stability. The aim of the project is to develop an efficient Cu based catalyst for selective hydrogenation of acetol to propylene glycol. Different copper precursors were tested, and solvent were optimized. The carbon nanofiber was also used as a support due to its inertness and easy of surface modification. The carbon surface structure on the catalytic performance were investigated.

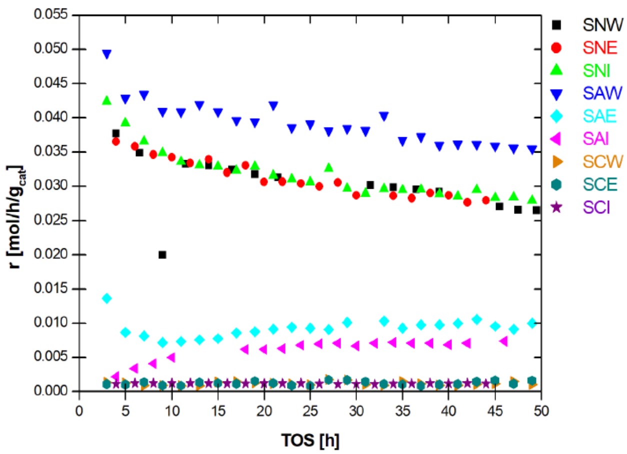


Figure xx, Hydroxyacetone reaction rate at 240 °C, 6 bara, molar fraction HA/H_2/H_2O/N_2 = 0.07/0.57/0.3/0,06, SV = 0.14 g HA gcat^{-1} min^{-1}.

It was found out that the Cu supported on silica prepared with copper acetate in water gave the highest reaction rate. Catalysts prepared with copper nitrates all have the same reaction rate but slightly lower than copper acetate. For copper nitrate precursor, the solvent seems do not influence the final activity of the catalysts. The results showed that copper acetate with water solvent could be a good alternative to copper nitrate to prepare catalyst since subsequence heat treatment may pose safety concerns when using nitrate as precursor. In terms of stability, the pristine carbon nanofiber supported catalysts are more stable compare with SiO_2 supported catalysts. Isopropanol solvent gave highest reaction rate, while water as a solvent gave highest PG selectivity.

New PhD student Zhihui Li was recruited in Nov 2021. She will work on project dealing with catalyst development and pilot testing of copyrolysis of biomass and plastics to produce stabilized biooil for coprocessing in refinery. The industry partners are Equinor and Quantafuel.

[1] https://blog.topsoe.com/bio-based-chemicals-one-step-closer-to-commercial-breakthrough

SP3: Biochemical Processes
SP Leader: Anikó Várnai

WP3.1	Pretreatment and Fractionation (Mihaela Tanase-Opedal, RISE PFI)	TRL: 3-5
WP3.2	Enzymatic Saccharification (Anikó Várnai, NMBU)	TRL: 1-6
WP3.3	Fermentation (Alexander Wentzel, SINTEF Industry)	TRL: 2-5
WP3.4	Anaerobic digestion and gas upgrading (Michał Sposób / Lu Feng, NIBIO)	TRL: 1-5

Background and approaches

This value chain focuses on applying biotechnology-based approaches to convert relevant biomass to biofuels and value-added chemicals. Softwood, such as Norway spruce, which constitutes Norway's largest proportion of land-based plant biomass, is known for its resilient structure and complexity and, therefore, has seldom been considered as feedstock for the biochemical production of biofuels. Biochemical conversion of biomass for 2nd generation bioethanol production is currently available commercially for perennial agro-based biomass. Based on these processes, the primary target of this subproject is to establish economically viable conversion of Norway spruce to a variety of biofuels (including ethanol, long-chain alcohols, microbial oil and methane) and biomaterials (lignin- and cellulose-based materials but also various fermentation products), employing important recent technological improvements in the field. Depending on the maturity of the technology, the WPs operate at varying technology readiness levels (TRLs), from formulation and verification of novel concepts to R&D and demonstration of technologies at pilot and demonstration scale, as indicated in the header above.

In the first step of the process, i.e. pretreatment, we focus on processing technologies that enable selective separation of lignin, hemicellulose and cellulose, and thereby facilitate efficient downstream use of all main constituents of lignocellulose feedstocks. In the following saccharification step, our target is to improve the currently suboptimal conversion yield and efficiency by identification of enzyme activities that are critical for softwood conversion and of process design that enables efficient use of novel oxidative enzymes. Next, we will assess a large collection of fermenting bacteria and oleaginous fungi for their potential to convert the solubilized sugars to short-chain alcohols, including ethanol, and microbial oil, respectively, in an industrially feasible way. Complementarily to this process, softwood with or without pretreatment will be subjected to anaerobic digestion to produce biogas. Here we will focus on enhancing biological methanation of biogas by optimizing process conditions and consider sorption-enhanced reforming of biogas for the industrially competitive production of hydrogen. In connection with SP5, we will assess the choice of fermentation technology, including the end product, and whether keeping the saccharification and fermentation steps separate or combining them is more feasible for softwood conversion with the selected technologies. Moreover, we will further enhance process efficiency by utilizing residual side streams from the saccharification and fermentation steps for methane production by anaerobic digestion.

Highlights

Within *Pretreatment* (WP3.1), we have further optimized a pilot-scale reactor at RISE-PFI to carry out organosolv pretreatment with lignin displacement for lignin removal and co-operated with downstream activities in technology development and techno-economical assessment of selected conversion routes. Within *Enzymatic Saccharification* (WP3.2), we have established a combined biochemical and thermochemical conversion route (with WP2.3 *Thermochemical Upgrading*) that is based on the modification of biomass pretreatment to improve lignin reactivity in the pretreated feedstock. The modified lignin promotes oxidative cellulose depolymerization and enables efficient separation of the sugar fraction from a quasi-pure lignin-rich saccharification residue, which can be then upgraded into high quality pyrolysis oil. With respect to *Fermentation* (WP3.3), we are working with St1 to improve their process efficiency using simultaneous saccharification and fermentation, while we have selected the best oil-producing fungi and optimized growth conditions for biooil production. Activities in *Anaerobic Digestion* (WP3.4), have successfully increased methane productivity during biogas production by supplying hydrogen to biogas reactor.

We have also published several publications within prestigious journals, including scientific papers and conference presentations together with industrial partners and across SPs.

New Centre for Research-Based Innovation (SFI) - *Industrial Biotechnology*
In 2021, the recently awarded *Centre for Research-Based Innovation* (SFI) project Industrial Biotechnology (SFI-IB), financed by The Research Council of Norway, have continued hiring new personnel and ramped up activities. Håvard Sletta, SINTEF, is the Project Manager of the SFI-IB. Industrial biotechnology entails the industrial application of modern biotechnological methods, enzymes, and microorganisms for production of a very wide range of commodities, including chemicals, pharmaceuticals, food and feed ingredients, detergents, textiles, energy, materials and polymers. The complementary nature of the two Centres Bio4Fuels and SFI-IB provides an excellent platform for the diversification of product portfolio that may be created from Norwegian biomass, via the mutually beneficial interactions between the two Centres. As industrial biotechnology is globally anticipated to become a major driver for establishing a sorely needed sustainable bioeconomy, there is a tremendous international activity concerning the development of new technological capability, new application domains, optimization of production pipelines and product diversification. The interest from the research organisations and the industry partners in the Centre for Industrial Biotechnology reflects the urgent need for establishing a nucleation point for a nationally concerted orchestration of R&D&I that can substantially strengthen Norway's position in this field. The four research organisations in the Centre (SINTEF, NORCE, NMBU and NTNU) possess together the major competence and infrastructure base in industrial biotechnology in Norway, and all 14 industrial partners have industrial biotechnology as a key business area with clearly defined innovation needs for maintaining a competitive edge. These innovation needs are the reason for SFI-IB, and they will be addressed in a potent matrix of a nationally concerted competence base, nationally integrated state-of the-art biotech infrastructures, and nationally coordinated training of future employees with state-of-the-art knowledge in bioprocess technology. In tune with the needs of

the industry partners, SFI-IB focuses on four innovation domains (industrial enzymes, biocatalytic processes, fermentation and gas fermentation/bioprocessing), and thus become a major national instrument for creating real value from the substantial investments in focal infrastructure and competence building made in Norway over the last ten years. Project period: 2020-2028.

WP3.1 Pretreatment and Fractionation - Mihaela Tanase Opedal

In Bio4Fuels we have been working with developing a novel organosolv pretreatment process for selective fractionation of Norway spruce. Lignin extracted from acetone organosolv pretreatement process of Norway spruce has a high purity and abundance of reactive groups, which make this organosolv lignin suitable for production of high-value products. In this respect, manufacturing of lignin-based biocomposites could be a plausible option for replacing fossil oil-derived thermoplastic materials [1]. Additionally, biocomposites based on various biopolymers and reinforcing wood fibres have major potential for 3D printing operations, as we have recently demonstrated [2].

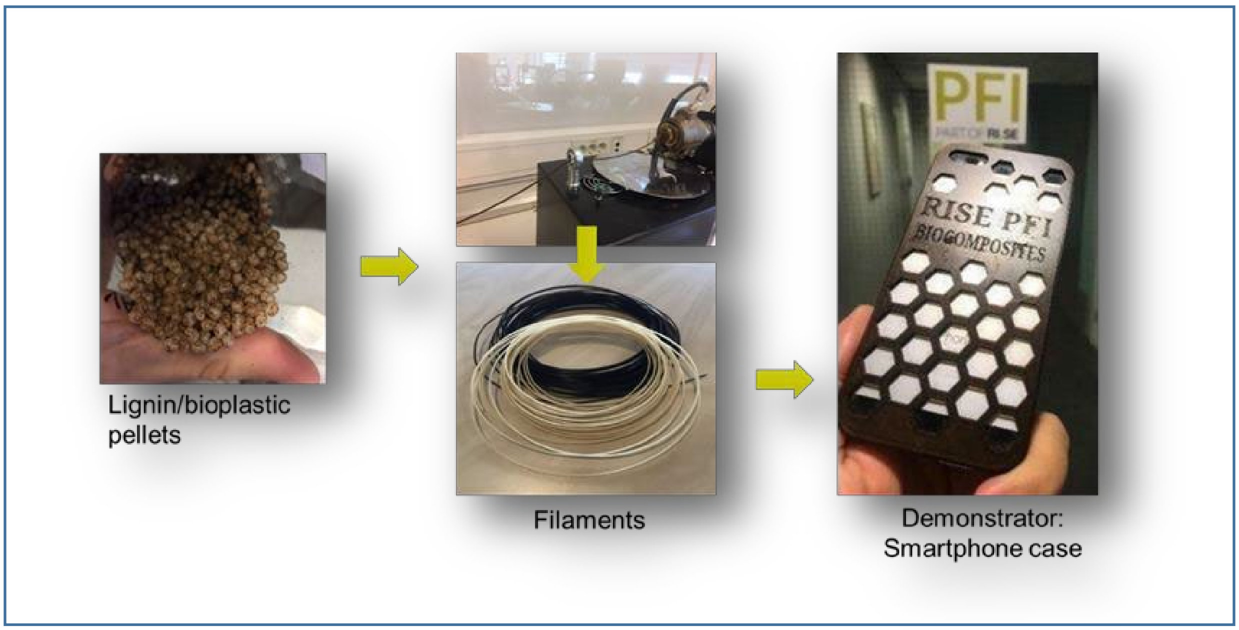
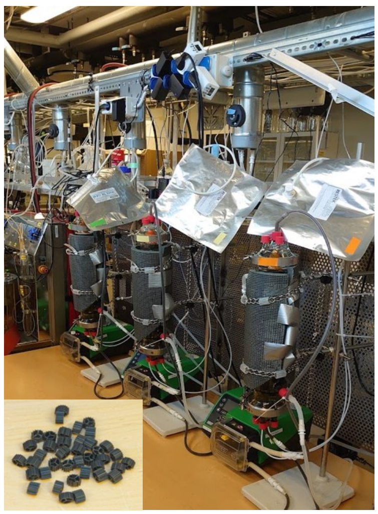


Figure 3.1.1: Left) PLA/lignin pellets. Middle) Extrusion of PLA/lignin filament. Right) 3D printed demonstrator of PLA/lignin biocomposites.

Reference:
1. Brodin, M.; Vallejos, M.; Opedal, M.T.; Area, M.C.; Chinga-Carrasco, G. Lignocellulosics as sustainable resources for production of bioplastics – a review. Journal of Cleaner Production, **2017**, 162, 646-664
2. Filgueira, D.M.; Holmen, S.; Melbø, J.K.; Moldes, D.; Echtermeyer, A.T.; Chinga-Carrasco, G. Enzymatic-assisted modification of TMP fibres for improving the interfacial adhesion with PLA for 3D printing. ACS Sustainable Chem. Eng., **2017**, 5 (10), 9338–9346.

WP3.4 Anaerobic digestion and Biogas upgrading - Michał Sposób/Lu Feng

In 2021, the main activities were to establish three lab-scale anaerobic trickle bed reactors (1 liter) for biogas upgrading to ex-situ upgrade of biogas (mixture of CO_2 and CH_4) to methane with hydrogen injection. Various of processing parameters were investigated in order to optimize the output methane. For instance, in this series test, we evaluated the impact of liquid circulation, feeding strategies (continuous vs non-continuous), input gas loading, and also compare three different biocarrier filter medium. Different to previous studies, here we attempted to deal with REAL biogas including both of CO_2 and CH_4 instead of CO_2 only to reflect the real condition. The maximum CH_4 content reach to close to 95% at the most optimal conditions.



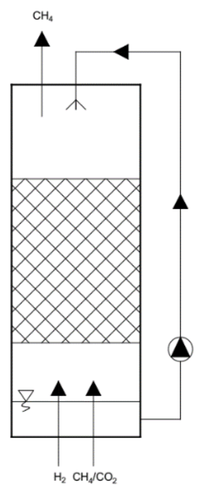


Figure. Lab-scale anaerobic trickle bed reactors and the reactor set-up

In 2021, we have also presented our results in obtained results in EUBCE 2021 and Biological Carbon Capture and Utilization (BCCU). A review paper was also published this year in 'Reviews in Environmental Science and Bio/Technology': Sposob, Michal, Radziah Wahid, and Keno Fischer. "Ex-situ biological CO2 methanation using trickle bed reactor: review and recent advances." Reviews in Environmental Science and Bio/Technology 20.4 (2021): 1087-1102.

WP3.2 Enzymatic Saccharification - Anikó Várnai

Within the Enzymatic saccharification work package (WP3.2), we work in close collaboration with Bio4Fuels partners Novozymes, Borregaard and St1 towards improving the efficiency of today's state-of-the-art enzyme blends in depolymerizing softwood-type feedstocks, which are in abundance in Norway. One of the key components of these enzyme blends is lytic polysaccharide monooxygenases (LPMOs). One of our targets is to develop industrial setups to improve the efficiency of commercial cellulase blends by harnessing the action of oxidative enzymes called LPMOs (lytic polysaccharide monooxygenases), a key component in today's enzyme blends, in a more efficient way than it is done in current industrial processes.

In 2021, we put more focus on engaging the Bio4Fuels stakeholders to a higher extent, as well as on better connecting our activities in WP3.2 with the activities of other WPs in the Centre (both within SP3 but also with other SPs) and of Bio4Fuels-associated projects. Our efforts are exemplified by the following set of works that resulted in scientific publications.

In early 2021, NMBU published a collaborative work with Lund University in the journal of *Biotechnology for Biofuels*, which was carried out within Bio4Fuels and the NFR-funded BIA (BIA-Brukerstyrt innovasjonsarena) project VASP—Value added sugar platform, a Bio4Fuels-associated project led by Borregaard. In this research paper, we measured the oxidation–reduction potential and hydrogen peroxide concentration in situ during cellulose saccharification with Novozymes' state-of-the-art LPMO-containing cellulase cocktail Cellic CTec2 at 1-L bioreactor scale and described how these correlate with LPMO inactivation and depletion of the reducing agent. A better understanding of the redox processes and enzyme inactivation taking place in the reaction enable us not only to maximize the benefit of LPMO action during saccharification and to overcome enzyme inactivation, but also to improve overall saccharification and lower cellulase loads, both of which would have beneficial consequences on process economics.

In addition, we published a method paper describing the analysis of oxidized sugar oligosaccharides generated by the action of LPMOs, with simplified operation and increased sensitivity for low abundant LPMO products, in the *Journal of Chromatography A*. This work is the result of a joint effort of Bio4Fuels and Enzymes4Fuels, an NFR-funded project that is associated with Bio4Fuels.

Finally, in a major cross-SP effort with WP2.3 *Thermochemical Upgrading*, we have established a combined biochemical and thermochemical conversion route that enables the recovery of a sugar-rich hydrolysate and the concomitant generation of a quasi-pure lignin-rich saccharification residue for pyrolysis. The process (see the Figure below) is based on the modification of steam explosion, a biomass pretreatment used by St1, with carbocation scavengers to improve lignin reactivity after pretreatment. We report that the modified lignin in the pretreated feedstock promotes oxidative cellulose depolymerization by LPMOs, leading to close to 100 % saccharification and that the generated lignin-rich saccharification residue can be upgraded into high quality pyrolysis oil. Importantly, our findings bring closer the prospect of an economically viable spruce-based biorefinery by combining biochemical and thermochemical conversion routes. The work will be published early in 2022.

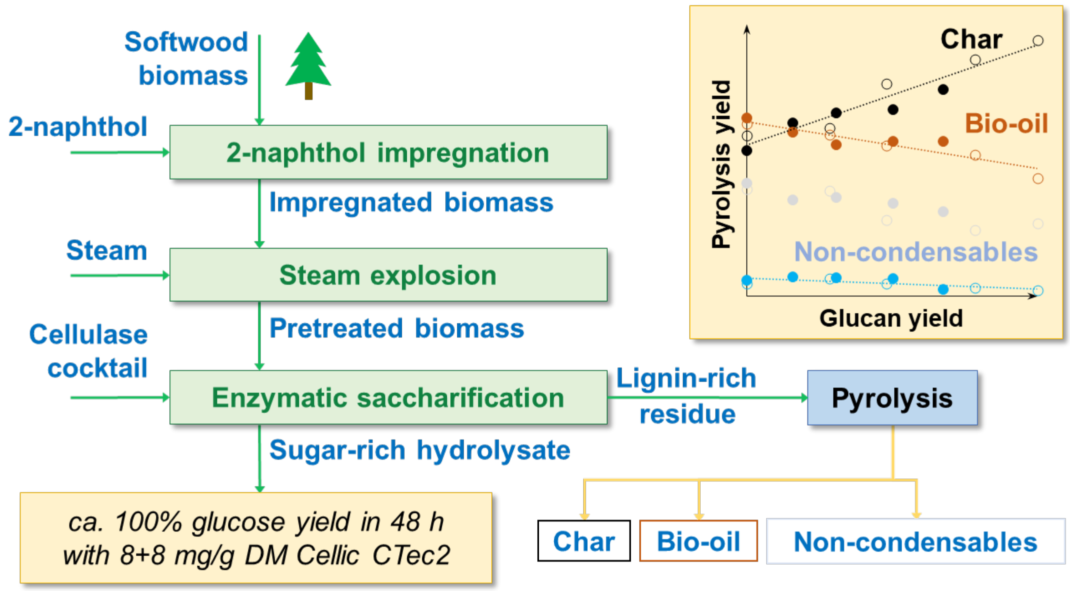


Figure showing the process scheme of the combined biochemical and thermochemical conversion route. Softwood impregnation with the carbocation scavenger 2-naphthol enabled complete saccharification of the pretreated feedstock, partly due to improved LPMO activity, and yielded high-quality saccharification rests for valorization by pyrolysis.

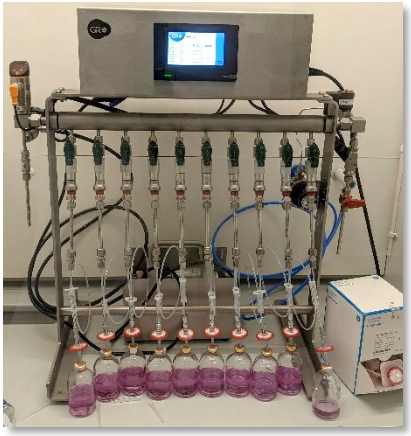
WP3.3 Fermentation - Alexander Wentzel

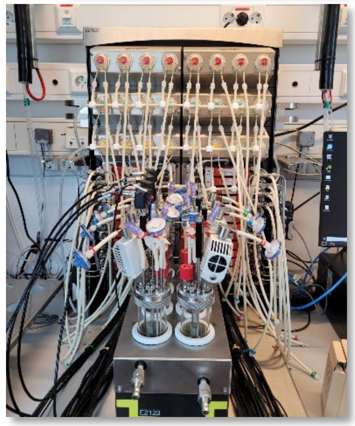
a) Mixotrophic Gas Fermentation

Combing existing sugar/glycerol-based, waste-feedstocks, with synthesis gas waste streams could be a pivotal game-changer in microbial mixotrophic fermentation.

A WP3.3 highlight has been to purchase and select strains suitable for this work, that have included model acetogens *Clostridium autoethanogenum*, *Clostridium scatologenes*, *Clostridium carboxidivorans* and *Moorella thermoacetica*. Each species is capable utilising synthesis gas ($H_2/CO_2/CO$) and can efficiently co-ferment this with a sugar-based substrate.

Several key pieces of equipment have been acquired at SINTEF Industry, Dept. Biotechnology and Nanomedicine. Firstly, the anaerobic gas exchanger will allow for rapid preparation of 120 mL serum flasks, that enable anaerobic fermentation to take place. Importantly, flasks will be able to be filled with custom gas mixtures, such as 80:20 H_2:CO_2, that will enable for reliable fermentation of gas. Thermophile, *M. thermoacetica* will also be used in the work test elevated fermentation conditions.





The next piece of equipment is the H.E.L BioXplorer 100 system, a gas fermentation reactor capable of 8 simultaneous fermentations, each with a 170 mL working volume.

All the above will be crucial in high-throughput, and deep analysis of fermentations that will test a variety of sugar-waste feedstocks, combined with syngas, or pure CO_2 streams.

The latter gas can be immediately tested, and later when SINTEF's gas-fermentation capabilities are operational, H_2 will be included into the gas composition feed.

b) Consolidated bioprocessing of lignocellulose for microbial lipids

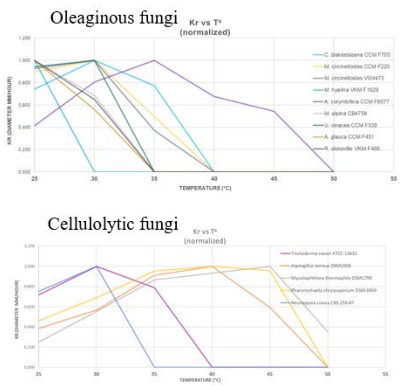
Simultaneous saccharification and fermentation of lignocellulose by thermotolerant oleaginous *Mucoromycota* and co-culture of them with the cellulolytic fungi for the production of microbial lipids

A set of promising oleaginous *Mucoromycota* strains selected based on the previous screening were further used for developing simultaneous saccharification and fermentation (SSF) of lignocellulose materials for microbial lipid production. The selected strains are *Mucor circinelloides*, *Cunninghamella blakesleana, Absidia glauca, Absida courelia, Mucor hiemalis, Rhizopus stolonifera, Umbelopsis vinaceae.* All starins are able to accumulate lipids in amount of 30 – 60% of the total biomass.

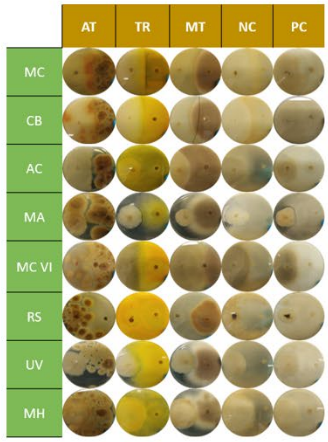
As a first step of SSF development, we performed thermotolerance experiment for identifying the highest temperature these fungi can tolerate. This will allow us to increase SSF temperature and by that increase enzyme activity and subsequently reduce final concentration of the enzyme used for SSF. Thermotolerance screening showed that *Absidia* strains are thermotolerant and able to grow well at 45°C which was also the optimal growth temperature.

Further, we performed screening for enzymatic activity and ability to secrete cellulase and β-gala ctosidase by the selected Mucoromycota fungi. The obtained results indicated the possible β-gala ctosidase activity for several Mucoromycota. Further we investigated compatibility between the selected Mucoromycota and cellulolytic fungi in order to evaluate a possibility for developing co-culture based SSF. This study is ongoing.

Screening of thermotolerance for oleaginous and cellulolytic fungi



Compatibility screening for coculture



SSF experiment in shake flasks

SP4: Process design and End Use
SP Leader: Morten Seljeskog

WP4.1	Gasification (Morten Seljeskog, SINTEF Energy)
WP4.2	Gas Conditioning (Edd Blekkan, NTNU)
WP4.3	Preparing for Piloting and Up-scaling (Klaus Jens, USN)

Background and approaches

Gasification is a thermochemical process where carbonaceous fuels are converted into combustible gases often referred to as syngas. There are different types of gasification technologies such as fixed- bed, fluidized-bed, and entrained flow. Depending on gasification temperature the ash inside the reactor is either molten or in a dry solid state.

The laboratory-scale reactor available for experimental activities in SP4 WP4.1, can be configured with simple geometric arrangements to operate both in entrained flow and in fixed/fluidized slagging bed mode, and is as such, a highly flexible instrument to study so-called new "fuels of opportunity", typically waste streams with high ash content and low market end-value.

Biomass gasification and subsequent fuel and chemicals synthesis allows for a seamless transition from fossil raw materials to a renewable economy with a limited need to replace existing infrastructure, since the resulting fuels can be designed to fulfil all technical requirements of conventional engines.

A main difficulty in the development of this route is the thermal efficiency of the overall process, where gas cleaning and conditioning is an important factor. There are two relevant gasification routes for fuel synthesis: entrained flow and fluidized bed gasification. Syngas from such processes must be converted to syngas with a high efficiency in order to maximize the thermal efficiency of the process. Hot gas cleaning would be the most economical and efficient route. However, the technology is immature and therefore the available technologies rely on liquid absorption, thus requiring gas cooling and subsequent reheating before further conversion. WP4.2 addresses the gas cleaning challenges in SP4.

Based on existing data from experimental work and simulations, reliable process models will be developed within SP4, for a complete gasification and gas cleaning system, eventually as a refinery integrated system. These models will be used to perform parameter variations to optimize process design. Flow behaviour will be simulated, while process concepts will be analysed using flow sheeting software. Finally, optimized process combinations will be established, based on both simulations and experimental results from all WP's and a theoretically optimal solution chosen for pilot plant design.

Biofuels derived from biological materials can replace petrol, diesel and other fossil-based fuels. Resent figures from Statistic Norway indicate that about 3.7 million solid m^3 of primary forest residues are left in the forests each year after harvest, without including natural felling + 800,000 tons of waste wood from households and industrial activities.

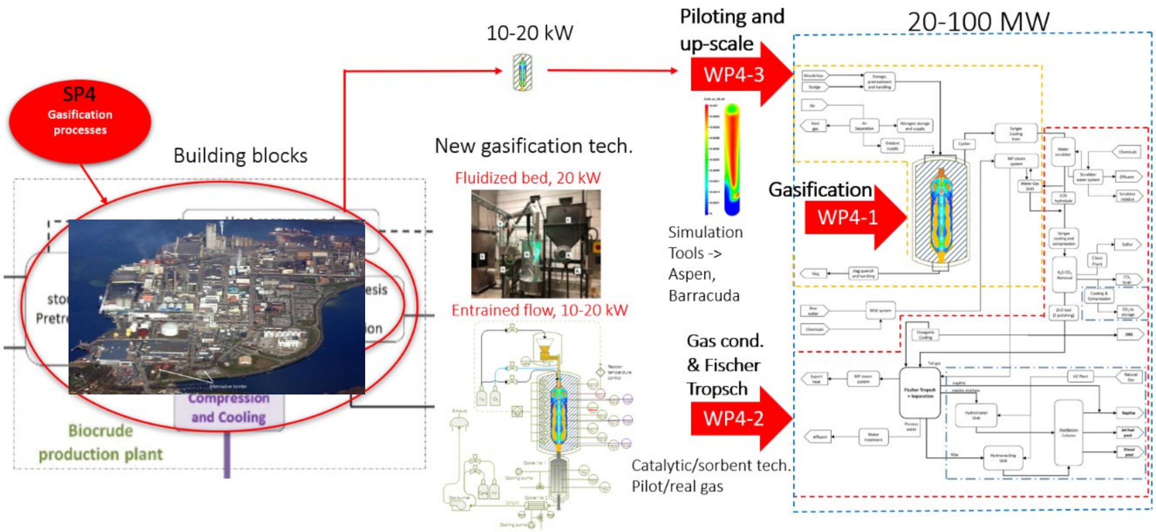


Figure: The main outcome of the work in SP4 is the specification of a full-scale industry cluster, integrated process solution, based on thermochemical conversion of selected carbonaceous feedstocks (by gasification, producing high-value clean syngas to supplement existing sidestreams…or converted to a liquid fuel through Fischer Tropsch).

2021 SP4 Gasification Processes: Several pilot-scale campaigns have been successfully performed on *Gasification* (WP4.1) in SINTEFs Entrained Flow Reactor (EFR) and in USNs bubbling bed reactor. USN is also building competence on CFD and system simulations related to the scale-up and integration of the final full-scale biofuel plant (WP4.3).

NTNU is progressing in their work on the development of catalytic technologies for *Gas Conditioning* (WP4.2) and have performed a number of related experimental campaigns. They are also developing numerical models for the same purpose.

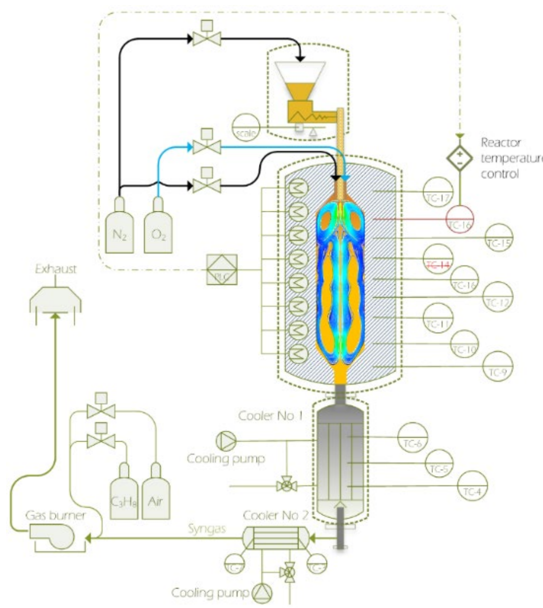
Achievements

- The results from the EFR show that the combination of increased reactor pressure (-> increased residence time and gas reactant concentrations) and using pure oxygen (-> increased residence time and oxygen concentration) instead of air as oxidizer allows us to achieve the same syngas properties as in a 10-fold larger atmospheric EFR with similar and higher % cold gas efficiency (CGE) Power, CGE fuel and carbon conversion CC for around the same λ and reactor temperature.
- Successful campaigns showing the capability of the EFR to handle milled lignin residues from ST1s production facilities in Finland resulting in a satisfactory syngas composition. Adding steam into the gasification process will allow us to tune the H2:CO ratio towards FT requirements.
- Fundamental research to build numeric models for the prediction of ash behavior using specialized software tools.

- A computational model based on Multi-Phase Particle-In-Cell (MP-PIC) approach was developed for both the bubbling bed and the entrained flow gasification reactor.
- A kinetics-based simulation model has been developed in the Barracuda® software and is currently being validated against the experimental results from USN and SINTEF on lignin gasification.
- A new model and method have been stablished to determine the critical amount of ash in fluidized bed systems, and thus provide the necessary tools to accomplish a more efficient and economical utilization of biomass in the future.
- Two peer reviewed publications.
- Two new gasification related projects; Biosyngas, NCS C+.
- Established a new catalyst system for tar and hydrocarbon reforming has been tested and optimized for this purpose
- Quantafuel, new industry partner via WP4.2 Edd Blekkan.

WP4.1 Gasification - Morten Seljeskog

Normal operation of the EFR is to preheat it, limited to maximum 100 °C/h, overnight, to the desired gasification temperature, which for all currently performed cases is around 1150 °C. For comparison with results produced by the 100 kW RISE vertical atmospheric flexi-fuel furnace (VAFF) at RISE Energy Technology Center in Piteå, both reactor temperature (T=1150 °C) and lambda has been set close to, or equal to, the conditions of the VAFF experiment (λ = 0.55). In later experiments, lambda was also varied while keeping the reactor temperature constant. Thermal input has varied between 10 – 21 kW, causing a rather large variation of the burner head nozzle velocity, the flow and recirculation patters as well as the residence time for both gas and particles in the reactor. Using air as oxidant at atmospheric conditions, the mean residence time varied between 1 – 3 s while using pure oxygen at pressurized conditions, the mean residence time is between 20-24 s, compared to the VAFF gasifier with around 8 s. Due to the 10-fold smaller scale at the SINTEF gasifier, we find two major differences. 1) The SINTEF gasifier is partly allothermal, meaning that energy is applied to the reactor in order to compensate for the relatively high heat losses that are normal at smaller scale. This is done through electrical heating of the reactor core in order to maintain a constant reactor wall temperature. 2) At atmospheric conditions and using air as oxidizer, the



residence time was much lower for the SINTEF gasifier. At 8 bar and with pure oxygen, the residence time is now much higher than in the VAFF reactor.

Besides the investigation of various potential "Future fuels", the main goal of SP4 in Bio4Fuels is to propose a full-scale gasification plant by the end of the project, meaningfully integrated into an existing Norwegian industry cluster. Therefore, understanding the scaling criteria of gasification reactors is one of the main learnings and outcome of SP4 - i.e., which operation variables to tune to achieve similar carbon conversion efficiencies and a satisfactory syngas composition (H_2:CO close to 2:1 and minimum CO_2 production) when performing the up-scaling.

Figure: A P&ID schematic representation of the entrained flow gasifier

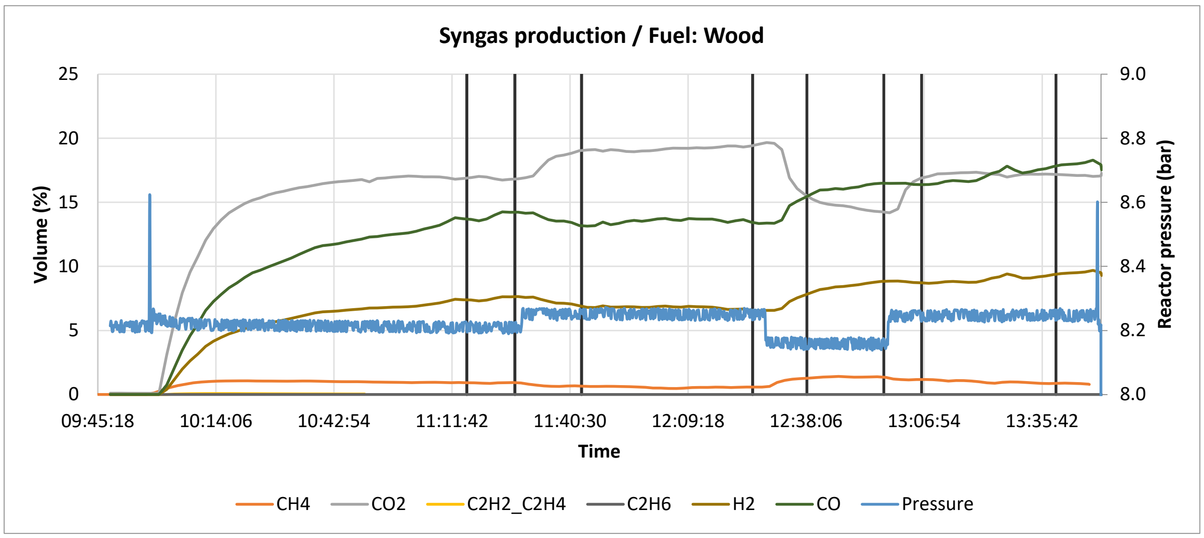


Figure: Typical syngas (vol% major species) production using 2.3-2.7 kg/h (12-14 kW) of woody powder at 8 bar/1150 °C/pure oxygen in burner

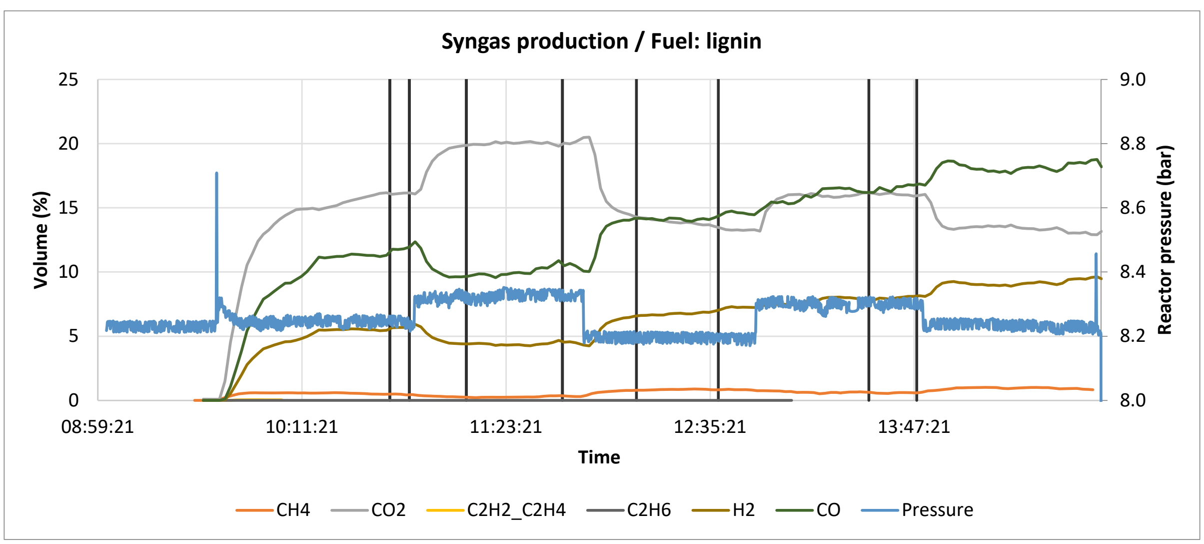
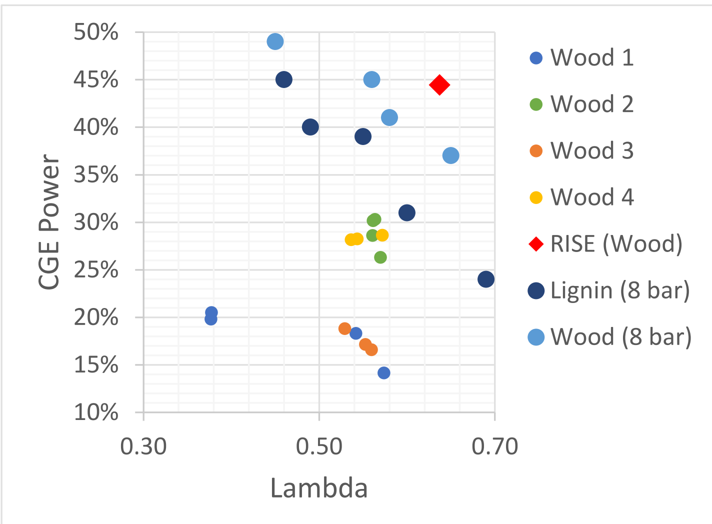
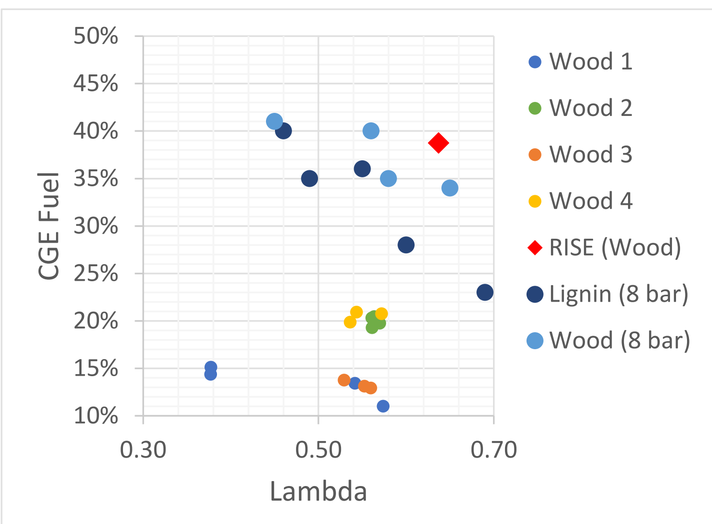


Figure: Typical syngas (vol% major species) production using 1.9-2.3 kg/h (11.5-14 kW) of milled lignin powder at 8 bar/1150 °C/pure oxygen in burner

The results from the EFR show that the combination of increased reactor pressure (-> increased residence time and gas reactant concentrations) and using pure oxygen (-> increased residence time and oxygen concentration) instead of air as oxidizer allows us to achieve the same syngas properties as in a 10-fold larger atmospheric EFR with similar and higher % CGE Power, CGE fuel and CC for around the same λ and reactor temperature.





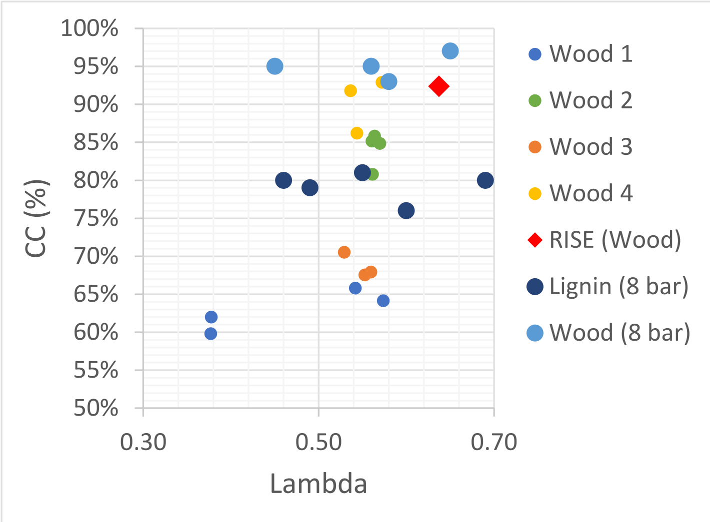


Figure: CGE (Cold Gas Efficiency, %) related to power and fuel and CC (Carbon Conversion, %) at varying operation conditions ($p_{reactor}$= 1 or 8 bar, $T_{reactor}$=1150 °C, $P_{reactor}$=10-20 kW, either air or pure oxygen in burner).

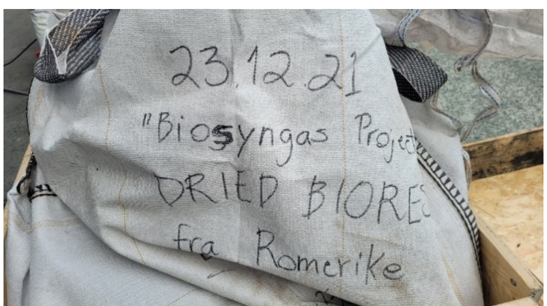


Figure: Exploring the smell and other rather delicate properties of an alternative "Fuel of opportunity"

WP4.2 Gas Conditioning - Edd Blekkan

The upgrading of the syngas from the gasifier represents a major part of the investment in a BTL plant. The activities include gas conditioning as well as gas conversion. The figure below shows an example of the work performed on the conditioning step: A new catalyst system for tar and hydrocarbon reforming has been tested and optimized for this purpose. The tar (in this experiment we use an aromatic model compound to represent the tar) has a significant influence on the catalyst activity and stability (part a). Changing the metal composition has a cost in terms of initial activity, but a very good stability can be achieved (part b).

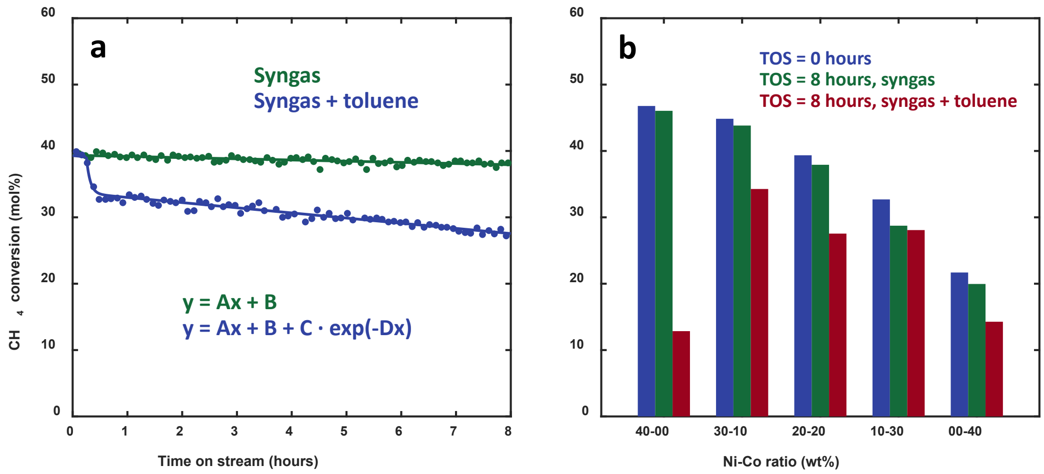


Figure: The catalyst is also active for the water-gas shift equilibrium reaction, and brings the composition close to equilibrium at these conditions.

WP4.3 Preparing for piloting and up-scale – Marianne Eikeland (Klaus Jens)

In May 2021 Nastaran Ahmadpour Samani, started her PhD in Computational particle fluid dynamics (CPFD) and process simulations modeling of biomass gasification reactors”. The work will be carried out at University of South-Eastern Norway (USN) as a part of the FME Bio4Fuel project.

The primary goal of this project is to establish computational particle fluid dynamics and process simulation models to generate insight into the framework needed for process design and pilot plant planning. The models will be used as a basis for the successful piloting of gasification technology for the production of biofuels or valuable chemicals from biomass.

PhD Student Nastaran A. Samani

The gasification reactor systems bubbling fluidized bed reactor and entrained flow reactor will be investigated. Different gasification reactor technologies and designs require different necessities. The PhD work will establish the differences for optimal plant operating parameters. CPFD models will be developed both for the bubbling fluidized bed gasifier at USN and the entrained gasifier at SINTEF Energy. The models will be validated by experimental results. The models will be used to analyze the results of parameter variations to optimize the process design.

Publications:

Timsina, Ramesh; Thapa, Rajan Kumar; Moldestad, Britt Margrethe Emilie; Eikeland, Marianne Sørflaten, *Computational particle fluid dynamics simulation of biomass gasification in an entrained flow gasifier. Chemical Engineering Science: X 2021; Volum 12. s. 1-14*

Timsina, Ramesh; Thapa, Rajan Kumar; Moldestad, Britt Margrethe Emilie; Eikeland, Marianne Sørflaten, *Methanol Synthesis from Syngas: a Process Simulation. SIMS EUROSIM 2021; 2021-09-21 - 2021-09-23*

SP5: Process design and End Use

- Identify most promising process configurations
- Efficient and clean end use

SP Leader: Bernd Wittgens

WP5.1	Modelling Tool for Biorefineries (H. Preisig, NTNU)
WP5.2	Techno-Economic Eval. / Scale of Economy (Bernd Wittgens, SINTEF Industry)
WP5.3	Product quality and End Use (Terese Løvås, NTNU)

Background and approaches

Sub-project 5 is divided into two activities, namely the need for a better model-based description of processes combined with An evaluation of their economical viability. The second major part considers the testing of biobased and zero-emissions fuels for primarily internal combustion engines.

The viability of processes products will be addressed using high level modelling tools for Biorefineries with an approach that requires biology, process technology, control and material properties to generate the predictive capabilities of the process models required for design and operations (first-generation process flowsheets used as basis for conceptual design of process instrumentation and control philosophy.). Techno-Economic Evaluation (Task 5.1.2)will be applied to the initial crude process design giving an early phase cost estimation followed by in-depth analyses of the best candidate processes. A framework for process design analysis and optimization (Task 5.1.1.) will be developed and jointly utilized for design and development of business cases for industrial implementation and thus generate insight into the framework needed for a successful commercialization of the most promising technologies.

Finally, the activities related to product Quality and End Use will aim to use state-of-the-art simulation and diagnostic tools to develop a framework for optimizing operational cost, energy efficiency and minimizing emissions from biofuel combustion. Focus will include regulated emissions such as NOx, CO, UHC and particulate emissions (soot). Fundamental combustion studies will be performed to map the overall performance of these fuels and ensure safe, clean and durable utilization of biofuels, including studies of new biofuels as well as an effects of blending into conventional fuels. Approaches will look to coupling state-of-the-art two-phase flow modelling and combustion chemistry with advanced engine and turbine measurements and optical diagnostics tools.

WP5.1 Modelling Tool for Biorefineries Heinz Preisig

Modelling chemical and biological processes is intrinsically a multi-scale as well as a multi-disciplinary problem that requires expert knowledge from different scientific domains. Modelling and control of biorefinery processes is particularly difficult due to their complexity as well as non-linearity, the heterogeneous as well as seasonally fluctuant feedstocks, and high uncertainty in bioprocess kinetics. The thereby caused uncertainties in the assessment and operation slows down the identification of the optimum process designs for industrial realisations of most biorefineries concepts, thus leading to a slow implementation of biorefineries. Correspondingly, the absence of robust, holistic, and predictive models directly transmits into a knowledge gap in design, assessment, and implementations.

Fortunately, the rapid evolution in technologies over recent decades initiated a radical change in problem-solving capacities and prospects, shifting more and more towards computer-aided model design and simulation. However, the increasing interest and expectations in model implementation place high demands on the modeller, thereby prompting a growing need for more effective and accessible model generation tools. The concepts of topology and ontology appear to be particularly convenient for addressing this: Each of them is intelligible by both, human and machine, and introduces easy-to-capture systematics as well as holistic views on the interiors of process systems. Together, implemented in a highly-automated software, they enable easy-to-access, comprehensible, transparent, and rapid model generation. Accordingly, **NTNU**'s Process Systems Engineering group works on the ontology-based, topology-utilizing model design environment **ProMo**, schematically depicted in Figure 1. **ProMo** utilises the facilities of the **Horizon2020** project **MarketPlace** (web page: https://www.the-marketplace-project.eu/). Based on the user-specified process structure in form of topologies, the **ProMo** suite assembles the mathematical model using ontologies and makes them available as an extension to the European Materials Modelling Council's **EMMO**, that is the European Material Modelling Ontology (web pages: https://emmc.info/ and https://emmc.eu/). **ProMo** enables the construction of process models using a graphical tool and generates simulation code. All these facilities are used to model biorefinery-relevant processes, which are assembled in a compound model library that can be utilised in the graphical editor to generate bio-process models. So far, the library covers steady-state as well as dynamic models for processes like, for example, flash tank, distillation, membrane filtration, adsorption, fermentation, pipes and valves, extraction, and fermentation.

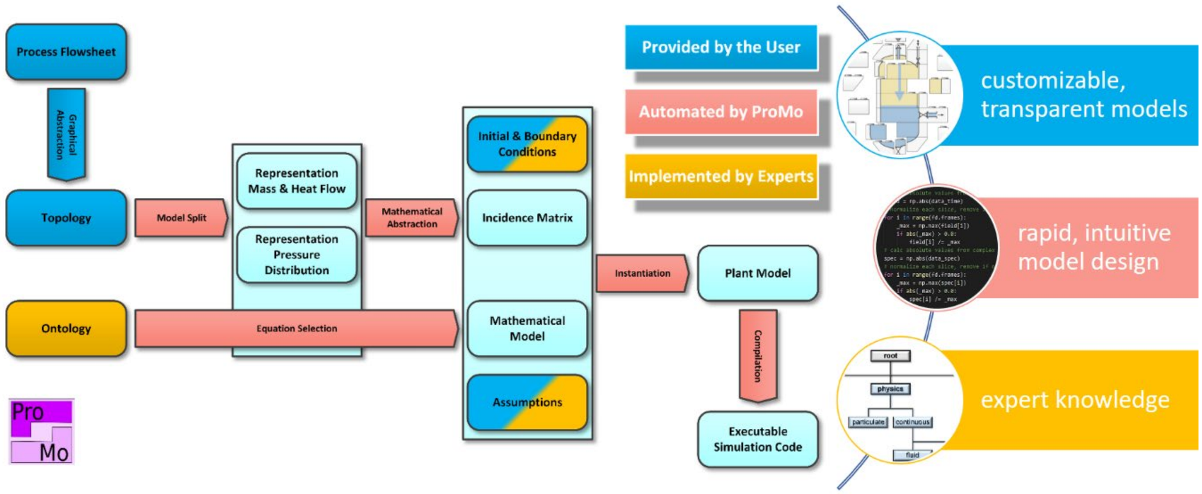


Figure 5.1.1: The composition of the modelling suite ProMo

The endeavour has made much progress in 2021, working on **ProMo**'s code splicing, model initialization, and open-source distribution via web access interfaces. Furthermore, 2021 was again a year in which the group substantively promoted the **Bio4Fuel** dissemination with journal papers like **Ontology-Based Process Modelling - with Examples of Physical Topologies** (Preisig, 2021) and **Systematic modelling of flow and pressure distribution in a complex tank** (Pujan & Preisig, 2022). The group also participated in conferences like **ESCAPE** and **WCCM** with papers, posters and talks like **Ontologies in computational engineering** (Preisig et al., 2021) and **Systematic Modelling of Transport Processes across Interfaces** (Pujan & Preisig, 2021). Additional to scientific publications, the **NTNU TekNat** blog post **Power to the Modeller** (Pujan & Preisig, 2021) (available at: www.ntnu.no/blogger/teknat/en/2021/04/13/) proofed to be a valuable approach for public dissemination. With our paper submission **Systematic Biorefinery Modelling with ProMo** (Pujan & Preisig, 2022) to the World Sustainable Energy Days 2022 (**WSED**) being invited for publication and oral presentation at **WSED**'s Young Energy Researchers Conference in April 2022, the next year continues where 2021 left off.

WP5.2 Techno-Economic Evaluation and Scale of Economy - Bernd Wittgens

The biochemical production of biofuels has been performed been performed for several years, some of these compounds can be used either as an replacement or additive in fuels for reciprocating engines (both gasoline and diesel) as well as jet engines, The most common biochemical derived fuels are biogas and ethanol. Both require adaptation of the engine, either conversion of e.g., a diesel engine to combined operation (diesel and gas) or adjustment of the fuel system for ethanol in gasoline engines to account for the different combustion performance.

Butanol and its ester butyl-butyrate are seen as a replacement and supplementary fuel in both diesel and jet engines. However, current production is not economical competitive with fossil derived fuel compounds.

During 2021 a complete pilot plant has been revised and refurbished for the simultaneous production of butanol and butyric acid. The initial plant design dates back to the NFR-project Ecolodge, additional financing through NORBIOLAB1 and 2 and FME Bio4Fuels made it possible to get a complete system into operation (see Figure 2). The process investigated is the conversion of sugars towards butanol and butyric acid, sub-sequent esterification with butanol to butyl-butyrate. For the process a co-fermentation of butanol and butyric acid is performed where some butyric acid is feed into the butanol reactor as co-feed to improve the butanol formation rate.

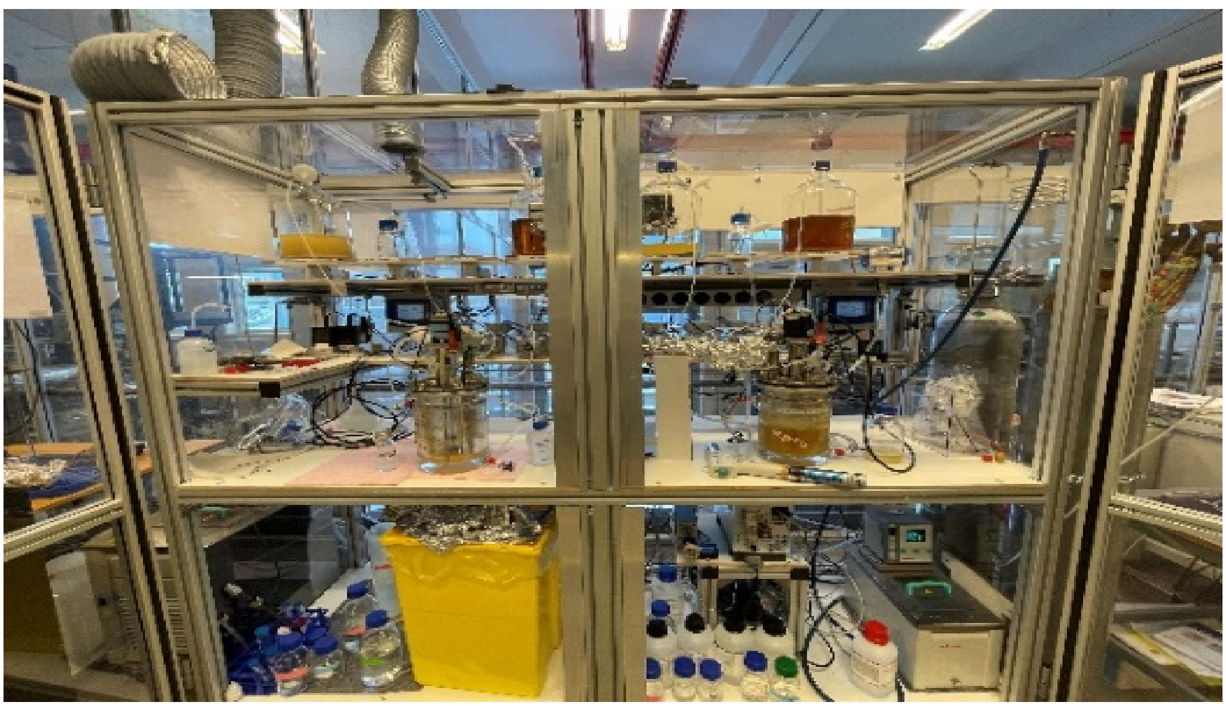


Figure 5.2.1: Revised pilot plant at SINTEF Industry

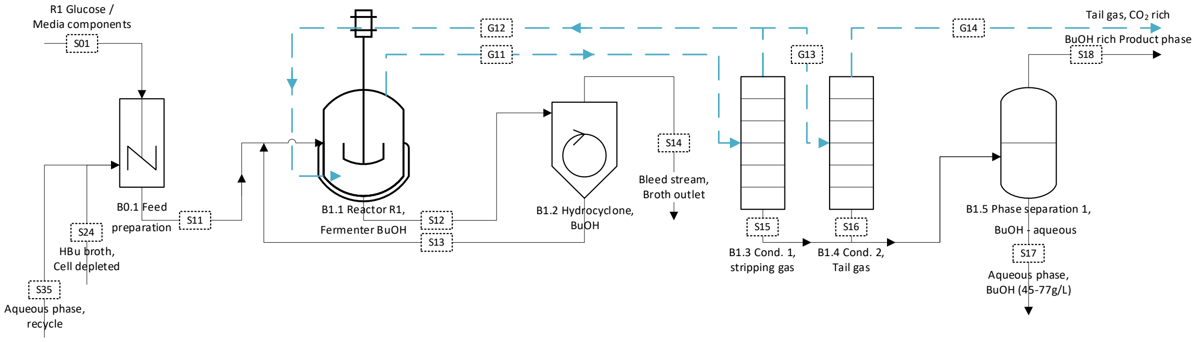


Figure 5.2.2: Butanol reactor

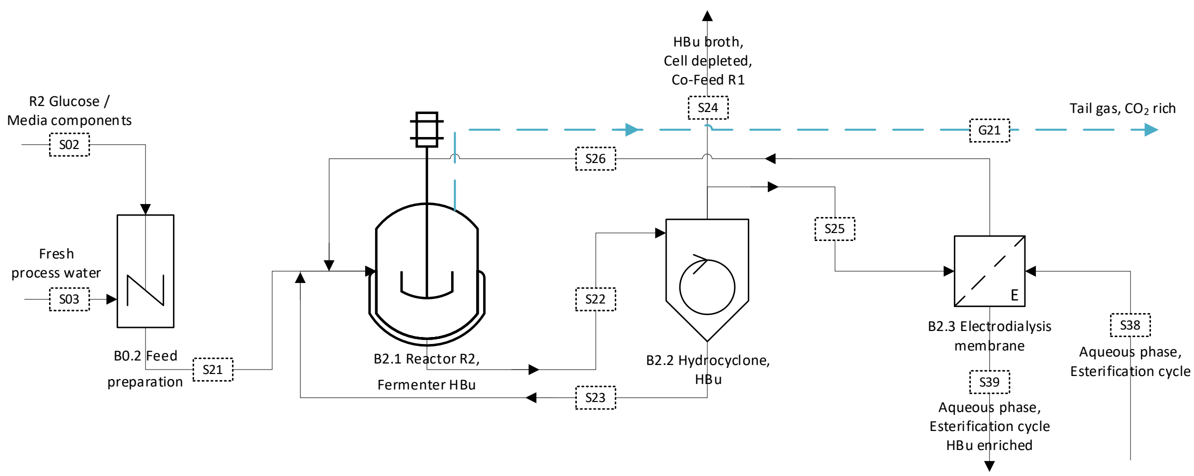


Figure 5.2.3: Butyric acid reactor

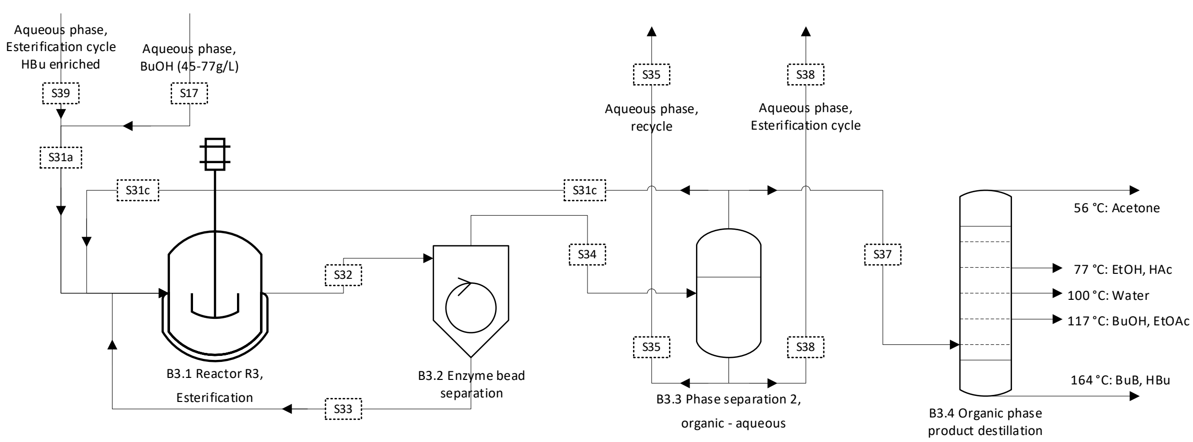


Figure 5.2.4: Esterification and final product recovery

Additionally to the work on the pilot plant, the complete flowsheet (fermentation (Figure 2 and Figure 3), recovery of butanol and butyric acid, esterification and product purification (Figure 4)) was implemented in the flowsheet simulator ASPEN. Subsequently, a technical and economical evaluation has been performed to identify the economical bottlenecks.

The technical and economical evaluation revealed a few challenges which will require further work. The current design is relatively complex from a design point of view to maximize resource efficiency, however this as influence on capital costs. Research is needed to evaluate potential increase in reaction rate (decrease equipment size, increase concentration and simplify product recovery) and a further simplification of the process itself. Another important area is the minimization of carbon losses through CO_2-emissions from the biochemical conversion, even though they are biogenic and part of a relatively short cycle, and improved utilization of carbon is needed to maximize fuel production. Results of the work are submitted to EUBCE2022-conference and a more elaborate paper is on-going.

WP5.3 Product quality and End Use - Terese Løvås

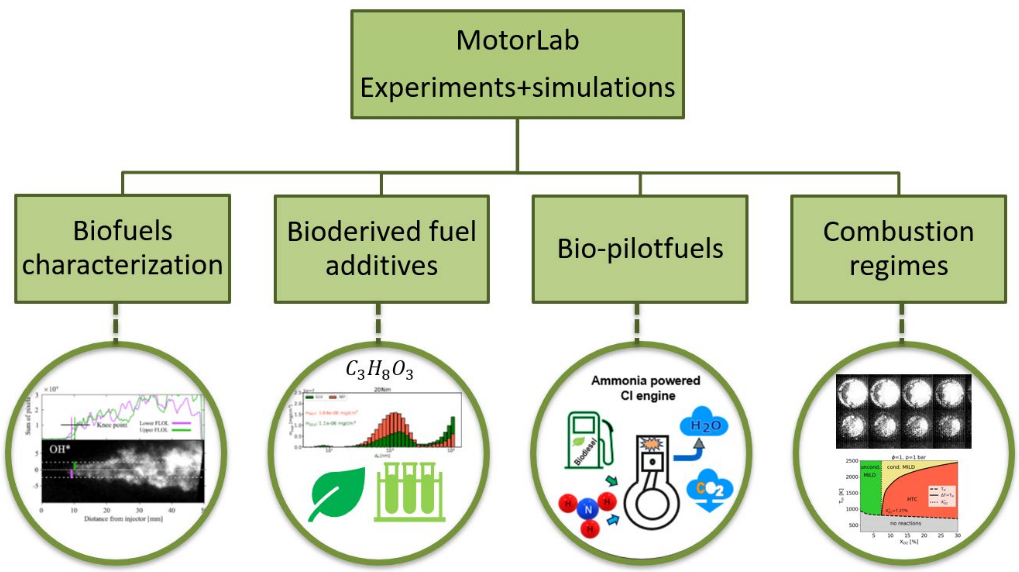


Figure 5.3.1. Four types of activities undertaken in the group related to bio-fuels investigations.

Comkin group at NTNU investigates liquid biofuels using both experimental and numerical techniques. **Experiments** are conducted using a simple single-cylinder engine and an optically accessible combustion chamber emulating real engine conditions. All the engines are instrumented, and various measurements can be taken: pressure trace, emissions (CO, CO2, NOx, THC) and soot, including particle matter size distribution. Different optical measurements techniques in the specially designed optical rig can be applied to characterize in-flame soot and spray flame behaviour. **Numerical studies** involve several approaches, from 3D fluid dynamic simulations to reduced-order models. They are used accordingly to cover a broad spectrum of problems solving the complexity of turbulent flow or predict emissions accurately using detailed chemical kinetic schemes.

Fuel surrogate is an important concept that links numerical simulations with real-world fuel. Surrogate fuels contain a limited number of pure components blended to match a target practical fuel's combustion and emission characteristics. Such composition is used in numerical simulation in conjunction with a validated chemical kinetic scheme, including the number of chemical reactions and species. Fuel surrogate can also be blended in the laboratory to produce the required volume to perform an experimental test.

Motorlab research studies can be categorized into four types of activities. **Biofuel characterization** focusing on its emissions and flame behaviour is the first and central task to assess biofuel performance. Additionally, **bioderived fuel additives** are considered to reduce emissions and soot in principle. Replacement of fossil energy sources with carbon-free fuels such as ammonia often requires ignition promoter where **bio-pilotfuels** can play a key role in minimizing a carbon budget. Novel concepts in combustion technologies employ favourable low-temperature **combustion regimes** (LTC) in which engines and fuels are co-optimized together.

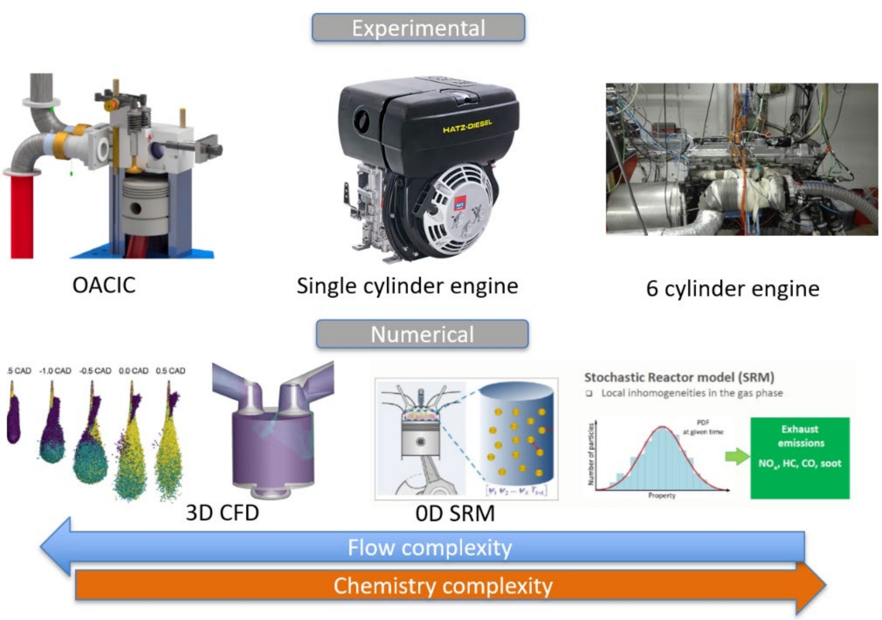


Figure 5.3.2. Experimental facilities and numerical methods used to investigate liquid bio-fuels.

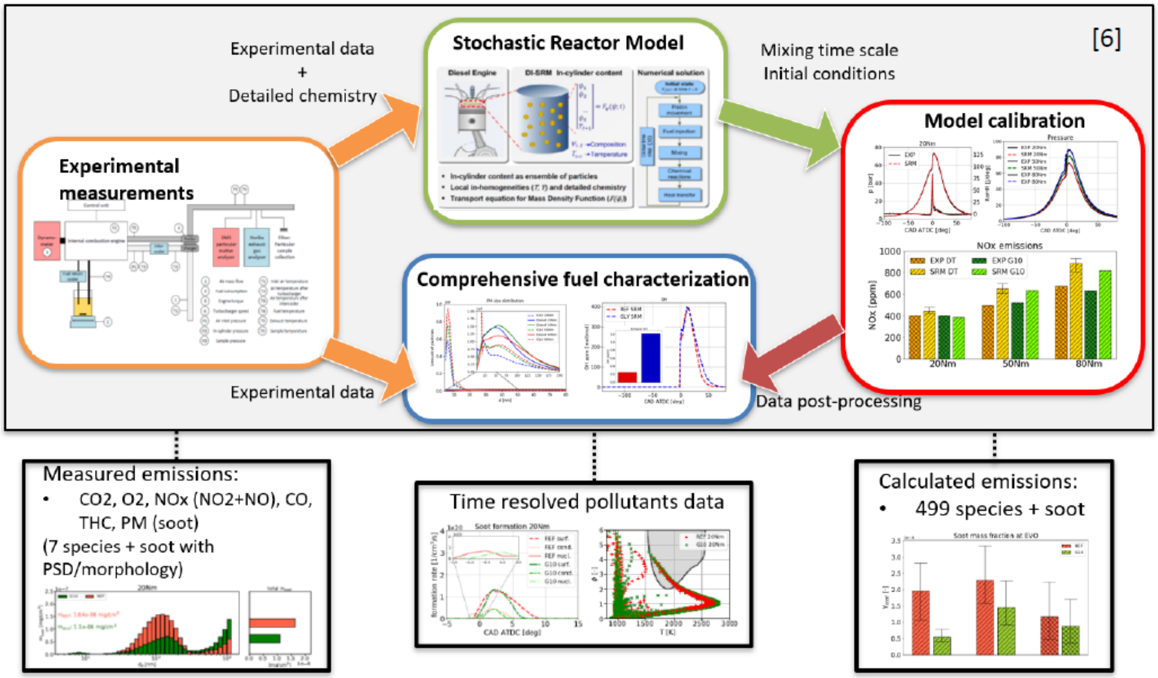
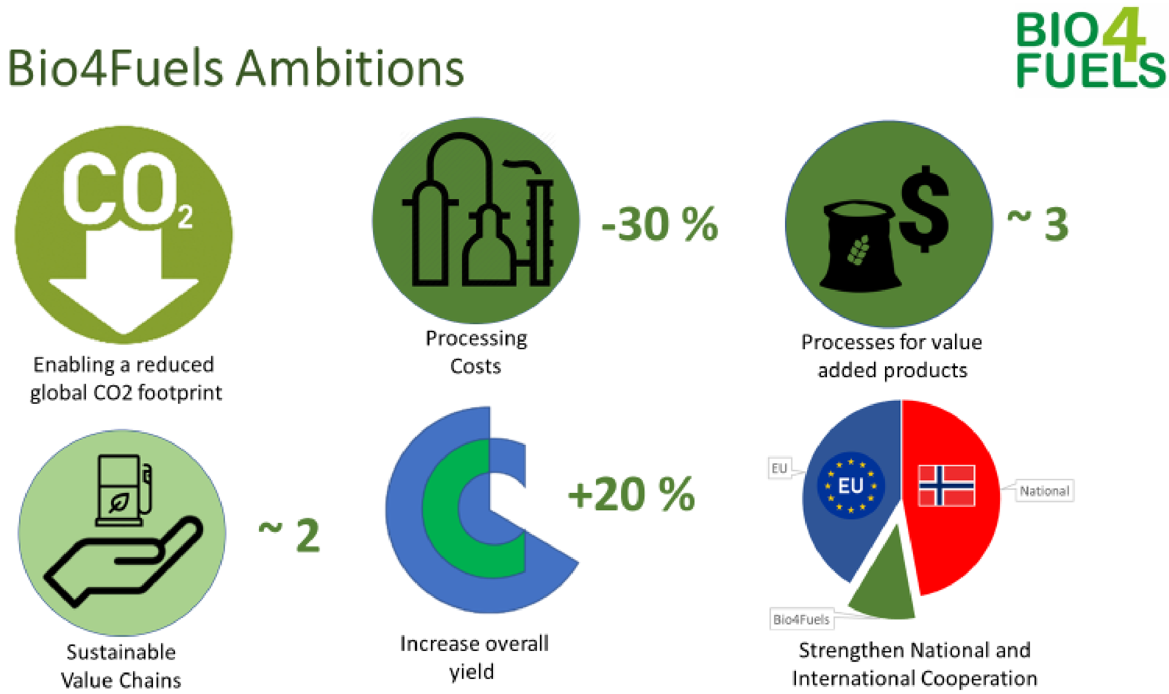


Figure 5.3.3. Schematic representation of the methodology employing experiments and numerical simulations for comprehensive fuel characterization. The results consider the study of glycerol as a fuel additive [1, 2].

Publications 2021:

1. Emberson D., Wyndorps J., Ahmed A., Bjørgen K.O., Løvås T., *Detailed examination of the combustion of diesel and glycerol emulsions in a compression ignition engine*, Fuel **291** (2021) 120147;
2. Lewandowski M., Netzer C., Emberson D., Løvås T., *Identification of combustion regimes in diluted compression ignition conditions,* 10th Eur. Combust. Meet. **N-242**, 14-15 April, Naples, Italy (2021) (virtual edition);
3. Lewandowski M., Netzer C., Emberson D., Løvås T., *Identification Numerical investigation of glycerol/diesel emulsion combustion in compression ignition conditions using Stochastic Reactor Model*, Fuel **310** (2022) 122246.

Bio4Fuels' Key Performance Indicators



International Cooperation

Bio4Fuels has from the very start of the operation of the Centre had a significant level of international cooperation at all levels. This presentation presents and overview of the wide range of International engagement though out the Centres.

International Agencies and Policy Forums

Internationale Arena	Activities	
IPCC - Intergovernmental Panel on Climate Change.	Active in contributing to the the IPCC (NTNU)	
IEA Bioenergy	Representation in a number of Tasks 32, 34, 39 and 45.	

ETIP Bioenergy – European Technology and Innovation Platform	Reprsenting Norway and coordinating input from industry and research partners in Norway	
European Bioenergy cluster	Take part in the dialogue with the EU commission and organise dedicated workships.	
Circular Bio-based Europe partnership program	Participation as industry and research member, contributing to the strategic research agenda	

International Stakeholders

With respect to the consortium of partners, the Centre has the strong involvement of a range of leading Nordic and European technology providers, given in Table below. This Nordic/European network is expanded through the involvement of associated partners, from the USA. These partners are active in the research activities and had a significant role in the Bio4fuels kick-off, providing an international perspective with respect to the state of the art. These partners will in the future operation of the Centre, will also be active as hosts for short mobility tours of students and researchers from the centre to obtain experience in specific areas in an industry context.

International Stakeholders	Country	Main interest
Biomass Technology Group	NL	Biomass to liquid (btl) pyrolysis
Johnson Matthey	UK	Chemical and catalytic processing of bio-feedstocks
Novozymes	DK	Enzymes for forest based biorefineries
Pervatech	NL	Membrane and separation systems for organic substrates
Steeper ENERGY	DK	Hydrothermal liquefaction
Lund Combustion Engineering ab	SE	Consultancy and software on combustion in motors
Preem	SE	Biofuels production and distribution in Sweden/Norway
Neste	FI	Upgrading of Biooil
Volvo Group Trucks Technology	SE	Truck engines powered by biofuels

Bio4Fuels' International Stakeholders

International Advisory Group

As an important part of the governance of the Bio4Fuels Centre, an International Advisory group has been established with the role of providing an international perspective and evaluation of the scientific activities of the Centre. As outlined under the structure and organisation of the Centre, the members of the Advisory Group have been selected to represent perspectives from Nordic, European and USA, in addition to having deep scientific insight to some of the main pillars of the Centre.

Networks

Combined in the Centre, most of the research partners have an extensive network of international contacts and collaboration. These include coordinating input to Mission Innovation, representation in EERA, involvement in mobilising input to the revision of the important SET plan for which the Bio4Fuels centre has been proposed as one of the Flagship projects in SET-Plan Action 8 (Renewable fuels and bioenergy) and participating and coordinating national input to the European Technology and Innovation Platform within Bioenergy (ETIP).

For Bio4Fuels, specific links are established with research groups and activities, as listed in the table below. at PNNL, Sandia and RTI in the USA. All partners were involved in the official kick-off of the Bio4Fuels centre and opportunities for collaboration within various international programs are being considered. Within the research topic of final end use of biofuels, Bio4Fuels partners are invited to receive information on the DOE funded project "Co-optima", through participation in the stakeholder Webinars.

EU Research Projects

Many of the research partners involved in the Centre have established a significant portfolio of European projects, both from FP7, H2020 and now within the new Horizon Europe. As of 2021, Bio4Fuels research partners were involved in at least 26 active EU projects, one of which is the Green Deal project PyroCO2. The projects cover different stages of the Bio4Fuels value chain in addition to different ranges of TRL scale, with several projects focussing on pilot scale demonstration of key technologies. The engagement of the Bio4Fuels research partners in so many EU projects is an indication of the level of scientific expertise of the work being carried out in the Centre.

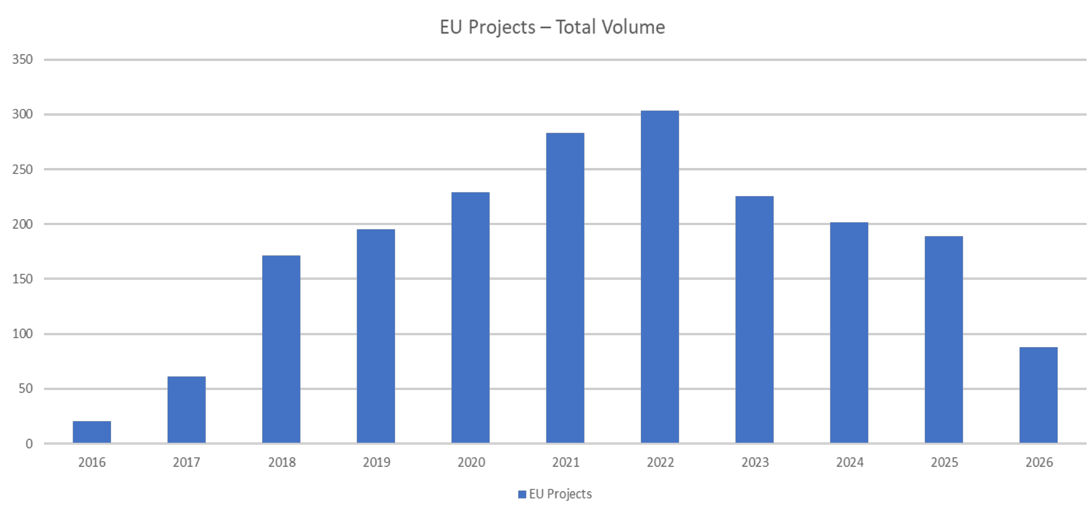


Figure: Overview of the development of the funding level of EU Projects associated with the partners of the Bio4Fuels Centre.

Selected examples of current running associated EU projects within Horizon 2020 and Horizon Europe

Recruitments and Education

PhD student Eirik Ogner Jåstad (WP1.3), NMBU

This PhD project is a part of the work package Energy, Fuels and Economics, WP1.3. The aim of my PhD-project is to use economic models to find implication of forest biofuel production in the Nordic countries. In 2018, had I focus on two studies, one that focusing on implications in the traditional forest sector if large amount of biofuel is produced within the Nordic countries. The second study investigates which level of subsidy needed for making biofuel production competitive with the fossil fuel.
The results show that the fossil fuel price must increase with 2-3x from today's level or the producers have to get an equivalent level of subsidy for making biofuel production competitive at today's raw material costs. Large investments of biofuel will give some structural changes in the traditional forest sector, the main findings are that harvest and utilizing of harvest residues will increase, similar will the net import to the Nordic countries increase simultaneously as the pulp and paper industry will reduce their production.
Supervisors: Per Kristian Rørstad and Torjus Folsland Bolkesjø, NMBU.
Eirik Ogner Jåstad defended his PhD degree on 1 December 2020.

PhD student Junhui Hu (WP1.3), NMBU

This PhD project will investigate the availability of forest-based biomass for biofuel production in both short term and long-term perspectives. The geographical border is expected to start with Norway and expand to Nordic countries and even Northern Europe.
The current annual harvest of forest is much less than the annual growth in Norway, and the government has set the target for total advanced biofuels used in road to 4% from 1st Jan 2020. This implies the huge potential and necessity for exploring the forest resources for producing the advanced biofuels from forest-based biomass, and this will play a vital role in phasing fossil fuel out in transportation sector and create a low carbon environment. However, the production of forest-based biofuel is far than mature due to various reason like technology immaturity, lacking policy support and raw materials competition.
The raw materials for forest-based biofuels are the biomass from harvest residues and by-products from sawmill, like chips, bark, sawdust, and shavings (as shown in the figure below). However, these materials will not only be used for biofuels, they are also in demand for other industries, like panels, pulp, and paper, as well as electricity and heat. Therefore, the availability and cost of forest-based biomass for biofuels becomes an important topic for discussing the cost and potential of biofuel production in the future.
Supervisor: Per Kristian Rørstad, NMBU
Junhui Hu (June) started as a PhD student in Bio4Fuels in October 2020.

PhD student Martina Cazzolaro (WP2.4), NTNU

This project is a part of the work package Catalysis for biomass conversion to chemicals, WP2.4 and aims to develop a stable copper-based catalyst for selective hydrogenation of hydroxyacetone to 1,2-propanediol, a major commodity chemical. Hydroxyacetone is a by-product of various biomass-based processes: biomass pyrolysis, sugar hydrogenolysis, glycerol dehydration. The main challenge of the project is the catalyst stability towards deactivation. In order to achieve this goal, carbon supports are tested. Platelet carbon nanofibers (PCNF) were prepared via carbon vapor deposition of CO and H_2 at 600°C over iron powdered nanoparticles. Various catalysts were prepared using PCNF and varying Cu precursors (nitrate, acetate, and basic carbonate) and impregnation solvents (water, ethanol, isopropanol). Characterization of the catalysts and catalyst activity tests will follow.

Moreover, surface treatment of PCNF will be explored, as surface oxidation, foreign-ion doping or confinement effect can be used to tune the surface properties of the carbon nanofibers. She also spent 3 weeks in Haldor Topsoe in June 2018 to learn their experiences and I enjoyed a lot the stay there.
Supervisors: Jia Yang and De Chen, NTNU.
Martina Cazzolaro will defend her PhD in 2022.

PhD Student Line Degn Hansen (WP3.2), NMBU

This PhD project is a part of the work package *Enzymatic saccharification* (WP3.2) and will focus on enzymatic saccharification of Norway spruce, with special attention on process optimization and integration. Biochemical biomass-to-liquid processes and the currently available commercial enzyme cocktails have been developed for grasses and hardwood materials and are not optimized for Norwegian biomass. In this project, we are going to identify enzyme components, such as redox and hemicellulolytic accessory enzymes, that are critical for efficient saccharification of softwood. Moreover, the recent discovery of the novel catalytic mechanism of lytic polysaccharide monooxygenases (LPMOs) creates an opportunity to considerably improve saccharification yields by optimizing process parameters including different feed strategies of H_2O_2, the enzyme's co-substrate. The obtained knowledge will be applied to allow better integration of the saccharification and fermentation steps. In addition, the effect of pretreatment type on saccharification and fermentation, regarding the composition of enzyme cocktail and process conditions, will also be assessed to achieve higher overall yields while minimizing process costs.
Supervisor: Aniko Varnai, NMBU
Line Degn Hansen will defend her PhD in June 2022.

PhD student Camilla Fløien Angeltveit (WP3.2), NMBU

This PhD project is a part of the work package Enzymatic saccharification (WP3.2) and will focus on lytic polysaccharide monooxygenases (LPMOs) role during enzymatic saccharification processes. The use of LPMOs together with the classical hydrolytic enzymes has been shown to greatly increase the depolymerization of lignocellulosic biomass. The ratio between hydrolases and accessory enzymes like LPMOs needs to be tailored for the specific substrates. Most commercial enzyme cocktails are tailored for agricultural waste biomass. In my PhD I will be focusing on creating better and more cost-efficient enzyme cocktails for depolymerization of softwood materials like Norway spruce.
Hydrogen peroxide appears to be the key to the successful depolymerization of polysaccharides by LPMOs. At the same time, the addition or production of hydrogen peroxide must be strictly controlled to hinder inactivation of the LPMOs. I will also investigate the role of LPMOs in simultaneous saccharification and fermentation processes (SSF) and determine the effect of hydrogen peroxide feed compared to in situ generated to improve the overall saccharification efficiency and yield.

Supervisor: Svein Jarle Horn, NMBU.

Camilla Fløien Angeltveit started as a PhD student in Bio4Fuels in August 2020.

PhD student Simona Dzurendova (WP3.3), NMBU

The PhD project is part of the work package WP3.3, Fermentation, where one of the objectives is to develop utilization of lignocellulose hydrolysates as a source of carbon for production of microbial lipids by oleaginous fungi fermentation. Oleaginous fungi are able to produce lipids with fatty acids profile similar to vegetable or fish oils. Oleaginous fungi are able to perform concomitant production of lipids and other valuable components as for example chitin/chitosan and polyphosphate. Lignocellulose hydrolysates are liquid materials rich in saccharides, but as shown by our studies, it also contains possible inhibitors of fungal growth. Therefore, there is a need to perform high-throughput screening of different fungal strains and growth conditions in order to find the most suitable fungal producer and optimise composition of lignocellulose-based media for the scale up of the process. Currently we are using synthetic growth media for the bioprocess development that allows us to have full control over the effect of certain micro- and macronutrients on the production of lipids and other valuable co-products, such as chitin/chitosan and polyphosphates. For the process development, we are using a micro-cultivation system combined with vibrational spectroscopy.

Supervisor: Volha Shapaval, NMBU.

Simona Dzurendova defended her PhD on 23 April 2021.

PhD student Cristian Bolaño Losada (WP3.3), NMBU

Developing consolidated bioprocessing of lignocellulose materials

IEA-roadmap reports that 20-30% of global energy demand could be supplied from the conversion of biomass. Lignocellulose biomass, due to its high abundancy and relatively low cost, has been positioned as one of the most important type of biomass for biofuels and biorefineries. Despite of almost a decade of research on the production of biofuels from lignocellulose biomass this process still suffers from the lower economical sustainability in comparison to the fossil-based processes.

In recent years it has been shown that lignocellulose materials can potentially be used to produce single cell oils (SCOs) by microbial fermentation and attention has been taken in microbial consortia or co-cultures with the aim to convert lignocellulose material to sugars directly in one step.

The main aim of the thesis is to develop a consolidated bioprocessing of lignocellulose material by utilizing microbial co-culturing and/or simultaneous saccharification and fermentation.

The main sub-tasks:

- Develop submerged fermentation of hydrolysed lignocellulose materials by oleaginous. filamentous Mucoromycota fungi as a reference bioprocessing of lignocellulose to SCOs.
- Investigate a possibility to co-culture cellulolytic fungi and oleaginous Mucoromycota fungi for SCOs production.
- Investigate to what extend simultaneous saccharification and fermentation process can be performed with a reduced amount of enzymes.
- To investigate a possibility to co-culture oleaginous fungi and algae by using hydrolysed lignocellulose materials.
- To utilize and develop application of vibrational spectroscopy for monitoring of CBP.

Supervisor: Volha Shapaval, NMBU.

Cristian Losada started as a PhD student in Bio4Fuels in August 2020.

PhD student Oscar Luis Ivanez Encinas (WP4.2), NTNU

Conversion of synthesis gas from fish waste gasification over cobalt catalysts

The increasing development of the global industry demands further energy production. The main source of energy are the fossil fuels and their use has been increasing every year. In 2016, more than 80 % of primary energy in the world was provided by fossil fuels. The new policies and future scenarios, where the increased prices of the fossil fuels and the demand of cleaner fuels, make necessary alternatives of fuel production.

Within these alternatives, the interest in the Fischer Tropsch Synthesis (FTS) increased in recent years. The FTS converts synthesis gas to hydrocarbons. The selectivity of the FTS can be optimized in order to obtain different products. Among these products, light olefins represent added value compared to fuels, which always will be the main product.

The syngas can be produced from different sources such as natural gas, coal or biomass. One interesting feedstock for the syngas is the biomass. This renewable energy source is abundant and opens the possibility to improve the total yield of different industries by using waste as a feedstock for the FTS. The total aquaculture production in Norway in 2018 was 1.354.941 tons, with 68% of the amount being editable. This represents an opportunity to valorize the fish waste in order to reduce the economic loses and improve the efficiency of the industries.

In this context, cobalt-based catalysts are going to be studied in the FTS with emphasis on olefin selectivity from biomass, BTL. The catalysts are going to be prepared by different synthesis methods, characterized by several standard and advance techniques, and tested in the FTS. The reaction condition choose for the project will favor the light olefin production. Due to the selection of fish waste as feedstock for the syngas, the project will be focused on the effect of several components present on this syngas source, which could affect the performance of the catalytic activity and selectivity. In addition, in order to improve the catalytic activity and selectivity, different metal oxides and noble metals will be studied as catalysts promoters.
Supervisor: Edd Blekkan, NTNU.
Oscar Encinas started as a PhD student in Bio4Fuels in August 2020.

PhD Student Ramesh Timsina (WP4.3), USN

This PhD project is a part of the work package Preparing for Piloting and Up-scaling, WP4.3. The main objective is to establish computational fluid dynamics and process simulation models as basis for the preparation of the pilot plant for biofuel production. The models will include pre-treatment of feedstock, thermal treatment, as well as separation and extraction steps. The thermal conversion technologies gasification, pyrolysis and hydrothermal liquefaction will be studied and evaluated. Experiences from studies in the other work packages will be used to make the framework for the simulation models, and a process flow sheet will be generated.

An important part of the project is to find overall process with minimal waste and high-energy yield for such process plants. Based on existing data from experimental work and simulations, reliable process models will be developed. These models will be used to analyse the results of parameter variations to optimize the process design. The process flowsheets will then be the basis for conceptual design operations. A theoretically optimal solution will be chosen for a pilot plant design.
Supervisor: Klaus Jens, USN. Ramesh Timsina defends his PhD in February 2022.

PhD student Ask Lysne (WP4.2), NTNU
Catalytic Steam Reforming of Hydrocarbons from Biomass Gasification

The increasing awareness of the effects of greenhouse gas emissions on the global environment has made the supply of renewable energy sources evident as a major challenge for future sustainable development. The International Energy Agency (IEA) has estimated a 42-50 % increase in the global energy demand by 2035 compared to the 2009 consumption. The transportation sector accounts for around 25 % of the global CO2 emission, where 90 % utilizes petroleum-based fuels. The substitution of currently applied fossil fuels by liquid fuels produced from renewable resources can hereby provide an efficient reduction of the global net CO2 emission. The annual growth of terrestrial plants stores more than 3 times the global energy demand, and biomass is in practice the only viable feedstock regarding production of renewable carbon-based liquid fuels. The successful integration of biomass gasification and Fischer-Tropsch synthesis in biomass-to-liquid fuel (BTL) technology is however limited by the intermediate gas conditioning of the synthesis gas (syngas) requiring the removal of inorganic, organic and particulate contaminants and adjustment of the composition in order to adapt to the subsequent catalytic fuel synthesis process step. The elimination of

tars is one of the most cumbersome challenges to the commercialization of such processes. The PhD project is addressing catalytic steam reforming, converting tars and lighter hydrocarbons to syngas as well as H2/CO/CO2 ratio adjustment by the water-gas shift reaction as part of this key gas conditioning step. The performance of a series of mixed oxide Ni-Co/Mg(Al)O catalysts prepared from hydrotalcite precursors are currently being investigated.
Supervisor: Edd A. Blekkan, NTNU. Co-supervisor: Kumar R. Rout.
Ask Lysne started as a PhD student in Bio4Fuels in August 2019.

PhD student Zhongye Xue (WP5.3), NTNU

Project title: *Experimental and Numerical Study of Low-Carbon Biofuels in Internal Combustion Engines*.
This project is focuses on a detailed experimental and numerical investigation of 2nd generation type biofuels in compression ignition engines. Various combustion parameters will be investigated with a focus on emissions of NO_x and soot. Fundamental experimental research on combustion of the biofuels will be carried out in collaboration with the current research team, employing a well-equipped engine laboratory and specially designed combustion rig with optical access for optical measurements. This enables detailed studies of the ignition and flame structure in the combustion chamber as well as particle formation. Matching the experimental data with results from detailed kinetic simulations using a stochastic reactor model will be an important part of the PhD project.
Supervisor: Terese Løvås, NTNU.
Zhongye Xue PhD started as a PhD student in Bio4Fuels in September 2020.

PhD student Nastaran Ahmadpour Samani (WP4.3), USN

Project title: *Computational particle fluid dynamics (CPFD) and process simulations modeling of biomass gasification reactors*.

The primary goal of this project is to establish computational particle fluid dynamics and process simulation models to generate insight into the framework needed for process design and pilot plant planning. The models will be used as a basis for the successful piloting of gasification technology to produce biofuels or valuable chemicals from biomass.

The gasification reactor systems bubbling fluidized bed reactor and entrained flow reactor will be investigated. Different gasification reactor technologies and designs require different necessities. The PhD work will establish the differences for optimal plant operating parameters. CPFD models will be developed both for the bubbling fluidized bed gasifier at USN and the entrained gasifier at SINTEF Energy. The models will be validated by experimental results. The models will be used to analyze the results of parameter variations to optimize the process design.

Supervisor: Marianne Sørflaten, USN
Nastaran Ahmadpour Samani started as a PhD student in Bio4Fuels in May 2021.

COURSES GIVEN BY BIO4FUELS RESEARCHERS

The researchers connected to the Bio4Fuels Centre are involved in various courses at NTNU, NMBU and USN. In this way, our research themes and results are present and made relevant for new students in Norway.

Courses at NTNU

Energy and Process Engineering, Specialization Project, 15 credits (ECTS)
Engineering Thermodynamics 1 7,5 credits (ECTS)
Thermal Energy, Specialization Project, 15 credits (ECTS)
Industrial Ecology, Project, 15 credits (ECTS)
Climate Change Mitigation, 7,5 credits (ECTS)
Nanotechnology, Specialization Project, 15 credits (ECTS)
Catalysis, Specialization Course, 7,5 credits (ECTS)
Chemical Engineering, Specialization Project, 7,5 credits (ECTS)
Chemical Engineering, Specialization Project, 15 credits (ECTS)
Industrial Chemistry and Refining, 7,5 credits (ECTS)
Reaction Kinetics and Catalysis, 7,5 credits (ECTS)
Experts in Teamwork - Biofuels - a Solution or a Problem? 7,5 credits (ECTS)
Biofuels and Biorefineries, 7,5 credits (ECTS)
Life Cycle Assessment and Environmental Systems Analysis, 7,5 credits (ECTS)
Climate Change Mitigation, 7,5 credits (ECTS)

Courses at NMBU

Biogas Technology, 5 credits (ECTS)
Bioenergy, 10 credits (ECTS)
Applied Biocatalysis and Biorefining, 5 credits (ECTS)
Energy and Process Technology Main Topic, 15 credits (ECTS)
Energy Policy and Markets, 5 credits (ECTS)

Courses at USN

Bachelor:
Bærekraftig ressursutnyttelse (Sustainable Resource Management), 10 credits (ECTS)
Organisk kjemi med biopolymere (Organic Chemistry with Biopolymers), 10 credits (ECTS)
Separasjonsteknikk (Separation Technology),10 credits (ECTS)
Energieffektivisering (Energy Efficiency) , 10 credits (ECTS)
Fornybare energisystemer (Renewable Energy Systems), 10 credits (ECTS)
Klima, miljø og LCA (Climate, Environment and LCA), 5 credits (ECTS)

Master:
Gas Purification and Energy Optimization,10 credits (ECTS)
Water Treatment and Environmental Biotechnology, 10 credits (ECTS)
Combustion and Process Safety, 10 credits (ECTS)
Energy Technology, 10 credits (ECTS)
Process Technology and Equipment, 10 credits (ECTS)

PERSONNEL AND RECRUITMENT

PERSONNEL

Name leader	Institution	Main research area
Rasmus Astrup (WP 1.1)	**NIBIO**	Land, Resources and Ecosystem processes
Francesco Cherubini (WP 1.2)	**NTNU**	Bio-Resources, Environment, Climate
Torjus Bolkesjø (WP1.3)	**NMBU**	Energy, Fuels and Economics
Kai Toven (WP 2.1)	**RISE PFI**	Pyrolysis
Judit Sandquist (WP 2.2)	**NTNU**	Hydrothermal Liquefaction
Roman Tschentscher (WP 2.3)	**SINTEF**	Thermochemical upgrading of bio oils
De Chen (WP 2.4)	**NTNU**	Chemo-catalytic conversion
Mihaela Opedal (WP 3.1)	**RISE PFI**	Pretreatment and Fractionation
Aniko Varnai (WP 3.2)	**NMBU**	Enzymatic Saccharification
Alexander Wentzel (WP 3.3)	**SINTEF**	Fermentation
Michal Sposob (WP 3.4 until October 2021) Lu Feng (WP 3.4 from October 2021)	**NIBIO**	Anaerobic digestion and gas upgrading
Morten Seljeskog (WP 4.1)	**SINTEF**	Gasification
Edd Blekkan (WP 4.2)	**NTNU**	Gas Conditioning
Klaus Jens (WP 4.3)	**USN**	Preparing for piloting and up-scale
Heinz Preisig (WP 5.1 until November 2021)	**NTNU**	Modelling Tool for Biorefineries
Bernd Wittgens (WP 5.2)	**SINTEF**	Techno-Economic Evaluation and Scale of Economy
Terese Løvås (WP 5.3)	**NTNU**	Product quality and End Use
Francesco Cherubini (SP1)	**NTNU**	Bio-resource, Environment and Climate
Judit Sandquist (SP2)	**SINTEF**	Liquefaction Processes
Aniko Varnai (SP3)	**NMBU**	Biochemical Conversion
Morten Seljeskog (SP4)	**SINTEF**	Gasification Processes
Bernd Wittgens (SP5)	**SINTEF**	Process design and End Use
Duncan Akporiaye	**SINTEF**	Centre Leader
Svein Jarle Horn	**NMBU**	Vice Centre Leader
Odd Jarle Skjelhaugen	**NMBU**	Project Leader
Janne Beate Utåker	**NMBU**	Administrator
Ann-Solveig Hofseth	**NMBU**	Financial Officer
Bente Poulsen	**NMBU**	Communication Officer
Haldis Bjerva Watson	**SINTEF**	Communication Officer
Camilla Fløien Angeltveit	**NMBU**	PhD Contact / Communication Officer

Recruitment

PhD Students with finance from the Bio4Fuels budget:

Name	Nationality	Duration	Gender	Topic
Angeltveit, Camilla F.	Norwegian	17.08.2020 – 16.08.2023	F	The role of LPMOs during enzymatic saccharification processes
Cazzolaro, Martina	Italian	01.08.2017 – 30.04.2022	F	Catalytic biomass conversion
Dzurendova, Simona	Slovakia	14.09.2017 – 23.04.2021	F	Bioconversion of lignocellulose materials into lipid rich fungal biomass.
Encinas, Oscar L. I.	Spanish	24.08.2020 – 24.10.2023	M	Conversion of synthesis gas from fish waste gasification over cobalt catalysts
Hansen, Line Degn	Danish	01.06.2017 – 15.06.2022	F	Optimization of enzymatic conversion of biomass to platform chemicals
Hu, Junhui	Chinese	05.10.2020 – 04.10.2023	F	Analyzing the role of biomass and biofuel in the Nordic energy, forest and transportation sectors towards 2050
Jåstad, Eirik Ogner	Norwegian	01.02.2017 – 31.12.2020	M	Models for Economic Assessments of Second-Generation Biofuel Production
Losada, Cristian B.	Spanish	10.04.2020 – 10.04.2023	M	Fermentation on developing multi-organism system for lipid production
Lysne, Ask	Norwegian	12.08.2019 – 11.08.2022	M	Catalytic Steam Reforming of Hydrocarbon Impurities from Biomass Gasification
Timsina, Ramesh	Nepal	24.09.2018 – 24.02.2022	M	Preparing for Piloting and Up-Scale
Xue, Zhongye	Chinese	16.09.2020 – 15.09.2023	M	Experimental and Numerical Study of Low-Carbon Biofuels in Internal Combustion Engines
Samani, Nastaran	Iran	01.05.2021 – 30.04.2024	F	Computational particle fluid dynamics (CPFD) and process simulations modelling of biomass gasification

Postdoctoral Researchers with financial support from Bio4Fuels budget

Name	Nationality	Duration	Gender	Topic
Lewandowski, Michal	Poland	04.04.2019 – 03.04.2022	M	Product quality and End Use
Morales, Marjorie	Chile	01.09.2019 – 31.08.2023	F	Bio-resource, Environment and Climate
Wahid, Radziah	Malaysia	01.03.2017 – 05.09.2019	M	Biogas

Other researchers 2021

Name	Institution	Name	Institution
Ljubisa Graviolic	IFE	Alex Nelson	IFE
Antonio Oliviera	IFE	Saimi Sultana Kasi	IFE
Roar Linjordet	NIBIO	Nicolas Cattaneo	NIBIO
Hege Bergheim	NIBIO	Carolin Fischer	NIBIO
Heikki Korpuen	NIBIO	Nils Egil Søde	NIBIO
Boris Zimmermann	NMBU	Achim Kohler	NMBU
Per Kristian Rørstad	NMBU	Aniko Varnai	NMBU
Erik Trømborg	NMBU	Volha Shapaval	NMBU
Yi-Kuang Chen	NMBU	Vincent Eijsink	NMBU
Hafeez Rehman	NMBU	Thales Costa	NMBU
Jon Gustav Kirkerud	NMBU		
Khare Shivang	NTNU	Otavio Cavalett	NTNU
Maren Haug	NTNU	Vinay Kumar	NTNU
Kenneth Aasarød	RISE Pfi	Jost Ruwoldt	RISE Pfi
Arild Blakstad	RISE Pfi	Cornelis van der Wijst	RISE Pfi
Ingebjørg Leirset	RISE Pfi	Marita Dørdal Helgheim	RISE Pfi
Johnny Melbø	RISE Pfi	Kristin Stensønes	RISE Pfi
Anne Marie Reitan	RISE Pfi	Javier C Romeo	RISE Pfi
Liang Wang	SINTEF Energy	Jørn Bakken	SINTEF Energy
Michaël Becidan	SINTEF Energy	Annar Bremnes	SINTEF Energy
Øyvind Skreiberg	SINTEF Energy	Mette Bugge	SINTEF Energy
Per Carlsson	SINTEF Energy	Helen Langeng	SINTEF Energy
Roger Khalil	SINTEF Energy	Gonzalo Del Alamo	SINTEF Energy
Inge Sannum	SINTEF Energy	Maria N P Olsen	SINTEF Energy
Jorunn Hølto	SINTEF Energy	Jacob Stang	SINTEF Energy
Petter Røkke	SINTEF Energy	Birger Rønning	SINTEF Energy
Jørund Aakervik	SINTEF Energy		SINTEF Energy
Inga Marie Aasen	SINTEF Technology	Olaf Trygve Berglihn	SINTEF Technology
Sidsel Markussen	SINTEF Technology	Sylvia Weging	SINTEF Technology
Ruth Elisabeth Stensrud	SINTEF Technology	Oxana Eide	SINTEF Technology
Merete Wiig	SINTEF Technology	Anders Brunsvik	SINTEF Technology
Torbjørn Pettersen	SINTEF Technology	Frank Ormøy	SINTEF Technology
Theresa Rücker	SINTEF Technology	Arne Erik Rekkebo	SINTEF Technology
Tor Erling Unander	SINTEF Technology	Morten Frøseth	SINTEF Technology
Terje Øyangen	SINTEF Technology	Pawel Piatek	SINTEF Technology
Francesca Di Bartolameo	SINTEF Technology	Morten Frøseth	SINTEF Technology

Tone Haugen	SINTEF Technology	Susan Maleki	SINTEF Technology
Ingvild Aune	SINTEF Technology	Malene Jønsson	SINTEF Technology
Anna Sofie Lewin	SINTEF Technology	Giang-Son Nguyen	SINTEF Technology
Lars Vik	SINTEF Technology	Kenneth Schneider	SINTEF Technology
Kari Hjelen	SINTEF Technology	Ina Beate Jenssen	SINTEF Technology
Kjell Domaas Josefsen	SINTEF Technology	Sidsel markussen	SINTEF Technology
Bendik Sægrov-Sorte	SINTEF Technology	Stig Rune Ulla	SINTEF Technology
Jody Veendaal	SINTEF Technology	Heiko Gaerter	SINTEF Technology
Marianne Eikeland	USN	Britt Moldestad	USN

MEDIA, PUBLICATIONS, SCIENTIFIC TALKS AND DISSEMINATION

Data from Cristin https://app.cristin.no/

COMMUNICATION AND OUTREACH 2021

Angeltveit, Camilla Fløien; Kommedal, Eirik Garpestad; Eijsink, Vincent; Horn, Svein Jarle.
The role of LPMOs during enzymatic saccharification of lignocellulosic biomass. Bio4Fuels days 2021; 2021-11-17 - 2021-11-18 NMBU

Barbosa Watanabe, Marcos Djun; Cavalett, Otávio; Cherubini, Francesco.
Brazilian sugarcane industry: current status, future trends and sustainability. Bio4Fuels Days 2021; 2021-11-17 - 2021-11-18 NTNU

Bolano Losada, Cristian; Zimmermann, Boris; Dzurendova, Simona; Kohler, Achim; di Bartolomeo, Francesca; Wentzel, Alexander; Markussen, Sidsel; Fjær, Kai; Eijsink, Vincent; Varnai, Aniko; Hansen, Line Degn; Horn, Svein Jarle; Shapaval, Volha.
Lignocellulose-based lipid production by fungal fermentation: A proof of concept on SSF and vibrational spectroscopy. Bio4Fuels days conference 2021-Drammen (Norway); 2021-11-16 - 2021-11-18 NMBU SINTEF

Bolkesjø, Torjus Folsland.
Biodrivstoff i fremtidens transportsektor. Arendalsuka; 2021-08-17 - 2021-08-17 NMBU

Bolkesjø, Torjus Folsland.
Hvordan omstille til en fossilfri transportsektor i Norge?. Fagseminar - Drivkraft Norge; 2021-05-28 NMBU

Bolkesjø, Torjus Folsland.
Nordic Clean Energy Scenarios. Arendalsuka 2021; 2021-08-17 NMBU

Bolkesjø, Torjus Folsland; Jåstad, Eirik Ogner; Trømborg, Erik; Rørstad, Per Kr..
Hvis vi velger vekk bioenergi, trenger vi mer gasskraft og vindkraft. Forskersonen.no 2021 NMBU

Cherubini, Francesco.
Bioenergy and biofuels for climate change mitigation: zooming from IPCC and IEA reports to a Nordic perspective. NFR Energiforskningskonferansen 2021; 2021-10-26 - 2021-10-26 NTNU

Cherubini, Francesco.
Biofuels for climate change mitigation: interlinkages, co-benefits and trade-offs with the agri-food sector and the environment. Miljødirektorat Lunch Seminar; 2021-10-25 - 2021-10-25 NTNU

Cherubini, Francesco.

Opportunities and challenges related to land use for production of biofuels - in Norway, the Nordic Region and globally. ZERO Seminar; 2021-02- 01 NTNU
Eijsink, Vincent.
Biomass, Biofuels and Biotechnology. SUSTAINABLE BIOECONOMY DEVELOPMENT 2021: Adaptation to Climate Change; 2021-05-21 - 2021-05-21 NMBU

Eijsink, Vincent.
Lytic Polysaccharide Monooxygenases (LPMOs) and other redox enzymes in polysaccharide degradation – fundamental and applied aspects. Lecture (digital); 2021-10-28 - 2021-10-28 NMBU

Eijsink, Vincent.
Nyheter fra (den bioteknologiske) forskningsfronten. NHO innlandet; 2021-06-03 - 2021-06-03 NMBU

Hansen, Line Degn; Østensen, Martin; Arstad, Bjørnar; Tschentscher, Roman; Eijsink, Vincent; Horn, Svein Jarle; Varnai, Aniko.
An example of combining biochemical and thermocatalytic conversion technologies. Bio4Fuels Days 2021; 2021-11-17 - 2021-11-18 NMBU SINTEF

Joseph, Prajin; Opedal, Mihaela Tanase; Moe, Størker.
The O-factor: using the H-factor concept to predict the outcome of organosolv pretreatment. Biomass Conversion and Biorefinery 2021 NTNU

Joseph, Prajin; Ottesen, Vegar; Opedal, Mihaela Tanase; Moe, Størker T..
Organosolv Pretreatment of Nordic Spruce for Biorefinery applications. Bio4Fuels Days 2021; 2021-11-17 - 2021-11-18 NTNU

Jåstad, Eirik Ogner.
The future role of forest-based biofuels: Industrial impacts in the Nordic countries. Bio4fuels days 2021; 2021-11-17 - 2021-11-18 NMBU

Kirkerud, Jon Gustav.
Hydrogen i framtidens europeiske energisystem. Fagmøte, Skagerak Energi; 2021-11-04 NMBU

Kohler, Achim; Solheim, Johanne Heitmann; Magnussen, Eirik Almklov; Blazhko, Uladzislau; Tafintseva, Valeria; Zimmermann, Boris; Brandsrud, Maren Anna; Dzurendova, Simona; Shapaval, Volha.
Model-based pre-processing and deep learning for correcting scatter effects in highly scatter-distorted infrared spectra of cells and tissues. French Chemometrics conference - e-chimiométrie; 2021-02-02 - 2021-02-03 NMBU

Kohler, Achim; Solheim, Johanne Heitmann; Magnussen, Eirik Almklov; Blazhko, Uladzislau; Tafintseva, Valeria; Zimmermann, Boris; Brandsrud, Maren Anna; Dzurendova, Simona; Shapaval, Volha.
Model-based pre-processing and deep learning for correcting scatter effects in highly scatter-distorted infrared spectra of cells and tissues. 11th International conference on advanced vibrational spectroscopy; 2021-08-23 - 2021-08-26 NMBU

Lewandowski, Michal; Netzer, Corinna; Emberson, David; Løvås, Terese.
Identification of combustion regimes in diluted compression ignition conditions. 10th European Combustion Meeting; 2021-04-14 - 2021-04-15 NTNU

Paulson, Bente.
Forskere kan skape mat og drivstoff av skogavfall. Forskning.no 2021 NMBU

Paulson, Bente.
Making the most of forestry waste. sciencenorway.no 2021 NMBU

Rajendran, Kishore; Rout, Kumar Ranjan; Chen, De.
HDO catalyst development. Kinetics and Catalysis yearly seminar; 2021-09-16 - 2021-09-17 NTNU

Rørstad, Per Kr.; Trømborg, Erik.
Skogplanting har positiv klimaeffekt. Dagens næringsliv 2021 NMBU

Sandquist, Judit.
Hydrothermal Processing - Concepts, Feedstocks and Modelling I. EUBCE - 29th European Biomass Conference & Exhibition 2021; 2021-04-26 - 2021-04-29 ENERGISINT

Sandquist, Judit.

Hydrothermal Processing - Concepts, Feedstocks and Modelling II. EUBCE - 29th European Biomass Conference & Exhibition 2021; 2021-04-26 - 2021-04-29 ENERGISINT

Sandquist, Judit; Tschentscher, Roman; Akporiaye, Duncan.
BIO4FUELS - Norwegian Centre for Sustainable Bio-based Fuels and Energy. Hydrothermal Liquefaction (HTL) in the green energy transition; 2021-01-28 - 2021-01-28 ENERGISINT SINTEF

Sposob, Michal; Aasen, Roald; Morken, John; Horn, Svein Jarle.
Forskere vil få mer ut av biogassen. nibio.no 2021 NIBIO NMBU

Sposob, Michal; Wahid, Radziah.
Ex-situ biomethanation in trickle bed reactor - counter-current and concurrent configurations comparison. Biological Carbon Capture and Utilization (BCCU); 2021-05-11 - 2021-05-11 NMBU NIBIO

Sposob, Michal; Wahid, Radziah; Horn, Svein Jarle.
Start-up of trickle bed reactor using inoculation with cow manure for ex-situ biomethanation. 29th European Biomass Conference & Exhibition; 2021-04-26 - 2021-04-29 NMBU NIBIO

Scientific Publications 2021

Data from Cristin https://app.cristin.no/

Publication	CiteScore 2020
Calvin, Kathrine; Cowie, Annette; Berndes, Göran; Arneth, Almut; Cherubini, Francesco; Portugal- Pereira, Joana; Grassi, Giacomo; House, Jo; Johnson, Francis X.; Popp, Alexander; Rounsevell, Mark; Slade, Raphael; Smith, Pete. Bioenergy for climate change mitigation: scale and sustainability. GCB Bioenergy: Bioproducts for a Sustainable Bioeconomy 2021 ;Volum 13.(9) s.1346-1371 NTNU	10.5
Dzurendova, Simona; Bolano Losada, Cristian; Dupuy--Galet, Benjamin Xavier; Fjær, Kai; Shapaval, Volha. Mucoromycota fungi as powerful cell factories for modern biorefinery. Applied Microbiology and Biotechnology 2021 s.101-115 NMBU	7.0
Dzurendova, Simona; Shapaval, Volha; Tafintseva, Valeria; Kohler, Achim; Byrtusova, Dana; Szotkowski, Martin; Márová, Ivana; Zimmermann, Boris. Assessment of Biotechnologically Important Filamentous Fungal Biomass by Fourier Transform Raman Spectroscopy. International Journal of Molecular Sciences 2021 ;Volum 22.(13) NMBU	6.0
Dzurendova, Simona. PhD Thesis: Sustainable fungal biorefineries: optimizing production of valuable metabolites in oleaginous Mucoromycota. Norges Miljø- og biovitenskapelige universitet 2021 (ISBN 9788257517977) 304 s. NMBU	
Dzurendova, Simona; Zimmermann, Boris; Kohler, Achim; Reitzel, Kasper; Gro Nielsen, Ulla; Dupuy--Galet, Benjamin Xavier; Leivers, Shaun Allan; Horn, Svein Jarle; Shapaval, Volha. Calcium Affects Polyphosphate and Lipid Accumulation in Mucoromycota Fungi. Journal of fungi (JoF) 2021 ;Volum 7.(4) NMBU	5.5
Jåstad, Eirik Ogner; Bolkesjø, Torjus Folsland; Rørstad, Per Kr.; Midttun, Atle; Sandquist, Judit; Trømborg, Erik. The future role of forest-based biofuels: Industrial impacts in the Nordic countries. Energies 2021 ;Volum 14.(8) NMBU BI ENERGISINT	4.7
Kadi, Adnan; Varnai, Aniko; Eijsink, Vincent; Horn, Svein Jarle; Lidén, Gunnar. In situ measurements of oxidation–reduction potential and hydrogen peroxide concentration as tools for revealing LPMO inactivation during enzymatic saccharification of cellulose. Biotechnology for Biofuels 2021 ;Volum 14. NMBU	9.9
Langseter, Anne Marie; Dzurendova, Simona; Shapaval, Volha; Kohler, Achim; Ekeberg, Dag; Zimmermann, Boris. Evaluation and optimisation of direct transesterification methods for the assessment of lipid accumulation in oleaginous filamentous fungi. Microbial Cell Factories 2021 ;Volum 20. NMBU	7.9
Leirpoll, Malene Eldegard; Næss, Jan Sandstad; Cavalett, Otávio; Dorber, Martin; Hu, Xiangping; Cherubini, Francesco. Optimal combination of bioenergy and solar photovoltaic for renewable energy production on abandoned cropland. Renewable Energy 2021;Volum 168. s.45-56 NTNU	10.8
Lewandowski, Michal; Netzer, Corinna; Emberson, David; Løvås, Terese. Numerical investigation of glycerol/diesel emulsion combustion in compression ignition conditions using Stochastic Reactor Model. Fuel 2021;Volum 310.(B) NTNU	
Ma, Jianyu; Mahmoodinia, Mehdi; Rout, Kumar Ranjan; Blekkan, Edd A.. Regenerable Sorbents for High-Temperature Desulfurization of Syngas from Biomass Gasification. Chemie Ingenieur Technik 2021 ;Volum 93.(6) s.949-958 NTNU SINTEF	2.4

Ma, Jianyu; Mahmoodinia, Mehdi; Rout, Kumar Ranjan; Blekkan, Edd Anders. The Impact of Operating Parameters on the Gas-Phase Sulfur Concentration after High Temperature Sulfur Sorption on a Supported Mo-Mn Sorbent. Reactions 2021 ;Volum 2. s.365-373 SINTEF NTNU	
Morales, Marjorie; Arvesen, Anders; Cherubini, Francesco. Integrated process simulation for bioethanol production: Effects of varying lignocellulosic feedstocks on technical performance. Bioresource Technology 2021 ;Volum 328. NTNU	14.8
Næss, Jan Sandstad; Cavalett, Otávio; Cherubini, Francesco. The land–energy–water nexus of global bioenergy potentials from abandoned cropland. Nature Sustainability 2021 ;Volum 4. s.525-536 NTNU	15.8
Pandey, Umesh; Runningen, Anders; Gavrilovic, Ljubisa; Jørgensen, Erik Andreas; Putta, Koteswara Rao; Rout, Kumar Ranjan; Rytter, Erling; Blekkan, Edd Anders; Hillestad, Magne. Modeling Fischer–Tropsch kinetics and product distribution over a cobalt catalyst. AIChE Journal 2021 ;Volum 67.(7) s.1-15 NTNU SINTEF	7.3
Preisig, Heinz A.. Modelling - Mechanistic reductionism extended with holistic empirical components. Computer-aided chemical engineering 2021 ;Volum 50. s.689- 694 NTNU	
Shang, Jingyuan; Fu, Guangbin; Cai, Zhenping; Feng, Xiang; Tuo, Yongxiao; Zhou, Xin; Yan, Hao; Peng, Chong; Jin, Xin; Liu, Yibin; Chen, Xiaobo; Yang, Chaohe; Chen, De. Regulating light olefins or aromatics production in ex-situ catalytic pyrolysis of biomass by engineering the structure of tin modified ZSM-5 catalyst. Bioresource Technology 2021 ;Volum 330. NTNU	14.8
Slaný, Ondrej; Klempová, Tatiana; Shapaval, Volha; Zimmermann, Boris; Kohler, Achim; ertík, Milan. Animal Fat as a Substrate for Production of n-6 Fatty Acids by Fungal Solid-State Fermentation. Microorganisms 2021 ;Volum 9.(1) s.1-17 NMBU	1.7
Sposob, Michal; Wahid, Radziah; Fischer, Keno. Ex-situ biological CO2 methanation using trickle bed reactor: review and recent advances. Reviews in Environmental Science and Biotechnology 2021 ;Volum 20.(4) s.1087-1102 NIBIO NMBU	10.4
Tafintseva, Valeria; Shapaval, Volha; Blazhko, Uladzislau; Kohler, Achim. Correcting replicate variation in spectroscopic data by machine learning and model-based pre-processing. Chemometrics and Intelligent Laboratory Systems 2021 ;Volum 215. NMBU	5.7
Timsina, Ramesh; Thapa, Rajan Kumar; Moldestad, Britt Margrethe Emilie; Eikeland, Marianne Sørflaten. Computational particle fluid dynamics simulation of biomass gasification in an entrained flow gasifier. Chemical Engineering Science: X 2021 ;Volum 12. s.1-14 USN	1.5
Urrego, Johana Paola Forero; Huang, Bo; Næss, Jan Sandstad; Hu, Xiangping; Cherubini, Francesco. Meta-analysis of leaf area index, canopy height and root depth of three bioenergy crops and their effects on land surface modeling. Agricultural and Forest Meteorology 2021 ;Volum 306. NTNU	8.9
Yeboah, Isaac; Feng, Xiang; Rout, Kumar Ranjan; Chen, De. Versatile One-Pot Tandem Conversion of Biomass-Derived Light Oxygenates into High-Yield Jet Fuel Range Aromatics. Industrial & Engineering Chemistry Research 2021 ;Volum 60.(42) s.15095-15105 NTNU	5.6
Yeboah, Isaac; Li, Yahao; Rajendran, Kishore; Rout, Kumar Ranjan; Chen, De. Tandem hydrodeoxygenation catalyst system for hydrocarbons production from simulated bio-oil: Effect of C-C coupling catalysts. Industrial & Engineering Chemistry Research 2021 ;Volum 60.(5) s.2136-2143 NTNU SINTEF	5.6
Østby, Heidi; Jameson, John-Kristian; de_Freitas_Costa, Thales; Eijsink, Vincent; Arntzen, Magnus Øverlie. Chromatographic analysis of oxidized cello-oligomers generated by lytic polysaccharide monooxygenases using dual electrolytic eluent generation. Journal of Chromatography A 2021 NMBU	6.9
	Average: 7.8

Associated Projects

In addition to the research activities financed directly within Bio4Fuels, the partners and stakeholders in the centre aim to stimulate and coordinate additional research and demo activities. These associated projects are focussed towards EU funding as part of the internationalisation strategy, as well as nationally based funding in order to provide a larger platform for addressing the overall challenges within the field. The range of associated EU and Nationally funded projects are listed below.

EU financed projects

Project	Total budget [mNOK]	Short Description of Project	Bio4Fuels Stakeholders involved
AC2OCEM	43	Accelerating Carbon Capture using Oxyfuel Technology in Cement Production - Biomass used instead of coal in the kiln)	NTNU (Indecol), Sintef Energy
SiEUGreen	70	Resource-efficient urban agriculture for multiple benefits – contribution to the EU-China Urbanisation Partnership	
EHLCATHOL	40	Chemical Transformation of Enzymatic Hydrolysis Ligning (EHL) with Catalytic Solvolysis to Fuel Commodities under mild Conditions	
BL2F	50	Biofuels from black liquor via HTL	SINTEF Energi, SINTEF AS, Neste
NextGenRoadFuels	46	Biofuels from sludge and organic waste via HTL	SINTEF Energi, Steeper
SET4Bio		Supporting the implementation of the SET Plan Action 8	SINTEF Energi
EBIO	42	Electrochemical upgrading o crude bio liquids	SINTEF Industry, BTG
4Refinery	60	Conversion of lignocellulosic Biomass via HTL and Pyrolysis to Advance Biofuels	SINTEF Industry
BRISK2	60	Transnational access of research infrastructure as well as research on monitoring, process design and costing	SINTEF Industry
LIBERATE	60	Conversion of Lignin to value added chemicals	SINTEF Industry
Pulp&Fuels	49	The Pulp & Fuel project, funded by the EU under Horizon 2020, studies how renewable fuel production can be integrated with pulp production to achieve positive synergies for the	SINTEF, RISE

		production of 2nd generation biofuels at a competitive price.	
SelectiveLi	5	Conversion of Lignin to value added chemicals	SINTEF Industry
Waste2Road	60	Conversion of Biogenic Waste via HTL and Pyrolysis to Advance Biofuels	SINTEF Industry, EGE
CONVERGE	49,9	Production of biomethanol through gasification-sorption enhanced reforming-membrane enhanced methanol synthesis	IFE
MEMBER	77,2	Production of hydrogen from biogas through membrane-assisted sorption-enhanced reforming	IFE, ZEG Power
FunEnzFibres	NMBU: 8,5	Enzymatic upgrading of cellulosic fibres with LPMOs (redox enzymes) for the production of textiles and nanocellulose	Borregaard, Novozymes
Oxytrain	30	Research on the mechanism, engineering and application of four different classes of oxygenases	
Baltic Biomass4 Value	30		
BESTER	26,9	Conversion of lignocellulosiic derived sugars to butyrate	SINTEF Industry
MarketPlace	8	MarketPlace is aiming at an integrated computing hub for simulatoins	
CUBE (ERC Synergy grant) to V.G.H. Eijsink	100	Unravelling the secrets of synthetic and biological Cu-based catalysts for C-H activation	
EEA-Baltic	8	Novel high-performance polymers from lignocellulosic feedstock	NTNU (Indecol).

NATIONALLY FUNDED PROJECTS

Project	Total budget [mNOK]	Short Description of Project	Bio4Fuels Stakeholders involved
BACS	24,5	Extraction of high value chemicals	SINTEF Industry Borregaard
BioCirc	6	Transnational Access of research Infrastrucutre	
Plastic &fuel	3		
AORTA	~1	Convertering makroalger til produkter	SINTEF Industry, Alginor

Bransjenorm for Biogass	0,8	The project aim to develope an industry standard for biogas	
SLUDGEFFECT	10,5	Life cycle effects from removing hazardous substances in sludge and plastic through thermal treatment	NTNU (Indecol). N.B.: Bio4Fuels explicitly provided a letter of support
BarkCure	10		NIBIO, SINTEF Industry
Bærekraftig biogass	22,8	The project aims increase biogas production in Norway by creating environmental- and resource optimal value chains for biogas, and strengthen the market position for biogas and bio fertilizers.	Oslo EGE / RBA, Lindum
FORBIOCHAR	8	Evaluating producing biochar from forest biomass.	skogeierforbunnet
BYPROVALUE	10	Production of lipids, chitin/chitosan, glucans and polyphosphate	Borregaard
Enable	25		
Enzymes4Fuels	10	Developing innovative enzyme technology for sustainable biofuels production with focus on lignin, hemicellulases and CBMs	Borregaard, St1
Foods of Norway	218	Centre for Research-based Innovation with focus on developing biorefining techniques to convert Norwegian bioresources to feed ingredients	Borregaard
LIGNOLIPP	12	Production of high-value lipids and chitin/chitosan	Borregaard
LipoFungi	10		
NorENS	11		
OIL4FEED	12	production of high-value lipids	Borregaard
OXYMOD	31,6	Optimization of oxidative enzyme systems for efficient conversion of lignocellulose to fuels and chemicals	Borregaard
Single Cell Oils	7		
Rocky	1	Upgrading residual fibres from saccharification for value-added products	Borregaard
Promac	35		
Climat Smart Forestry Norway	25		
Bio4Fuels	236,6		
PyroGass	31,5	Norske Skog Saugbrugs skal utvikle ny teknologi for samproduksjon av	Norske Skog Saugbrugs, Cambi, RISE PFI, USN

		biogassdrivstoff og biokarbon reduksjonsmiddel til produksjon av manganlegeringer basert på restråstoff fra papirproduksjonen	
Advanced Biofuels via Syngas	8,9		
B2A	20	Conversion fo biomass to aviation fuels	NTNU, SINTEF, St1
BioFT	12,8	Optimization of the process for production of fuels via Fischer-Tropsch synthesis	SINTEF Industry
CLD	10,1	High temperature gas cleaning throgh Chemical looping Desulfurization	SINTEF Industry
GasPro	16,7	Increase the energy efficiency of the entrained flow biomass gasification technology for bio-fuel production	NTNU, Dr Tian Li, Prof.Terese Løvås, SINTEF Energy
H2BioOil	11,8		
H2Biooil	10	Hydropyrolysis of biomass+catalytic upgarding	NTNU
MIRA	13,3		
NanoLodge	5,1	Development of a new reactor design integrating the biotech production of butanol, butyric acid, and their consecutive enzymatic esterification to butyl butyrate using innovative membrane technology	NTNU, SINTEF Industry
Bio4-7Seas	10,5	Biofuels for climate change mitigation in of deep-sea shipping	NTNU (Indecol). N.B.: Bio4Fuels explicitly provided a letter of support
BioPath	10	Advancing the understanding of regional climate implications of bioenergy systems	NTNU (Indecol)
Norwegian Seaweed Biorefinery Platform (SBP-N)	15		SINTEF, NTNU, NMBU
ReShip	15		
PyroGas	4		
NanoCat4Fuels	3,9		
GAFT			
BIOGREEN	6		

FLASH	9,9	Understand how ash elements physically behave in a gasification or incineration scenario, and specifically how the ash melting temperature and ash viscosity can be determined, modelled and predicated.	USN/ SINTEF Energy
TechnoSER	11,7	Technical optimization of the sorption-enhanced reforming process for hydrogen production	ZEG Power, IFE
CUBE (ERC Synergy grant) to V.G.H. Eijsink	100	Unravelling the secrets of synthetic and biological Cu-based catalysts for C-H activation	Unravelling the secrets of synthetic and biological Cu-based catalysts for C-H activation
Flex4RES	24		
Nordic Clean Enegy Sdenarios 2020	9		

ACCOUNTS 2021

Overview of the accounts for 2021, reported to the Research Council of Norway on 20 January 2022, approved 4 February 2022.

Project costs	Actual	Budget	Finance specification	Actual	Budget
Payroll and indirect expenses	40 416	41 975	In-Kind NMBU	6 292	4 538
Procurement of R&D services			Public Funding	11 076	15 578
Equipment	2 206	1 840	Private Funding	6 225	5 384
Other operating expences	2 890	2 300	International funding	3 875	1 625
			The Research Council	18 044	15 663
Total	45 511	46 115	Total	45 511	42 788

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Bio4Fuels Stakeholders

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CAMBI - recycling energy
Oslo
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Norske Skog
Statkraft
Statens vegvesen
Hyperthermics THE GREEN SHIFT REVOLUTION
Norges Skogeierforbund
ZEG Power
Borregaard
NORGES BONDELAG
UMOE
follorådet
novozymes Rethink Tomorrow
Trøndelag fylkeskommune
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btg biomass technology group
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