FME BIO4FUELS ANNUAL REPORT 2023

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

Johnson Matthey (JM): Scaling up biofuel production

Norwegian Centre for Environmentfriendly Energy Research

BIO4 FUELS

Contents

Norwegian Centre for Environment friendly Energy Research – The Research Council of Norway

From Bio4Fuels' Management

2023 has been a period when the urgency of deployment of solutions for sustainable transport fuels was fully acknowledged through a number of major announcements both by the Norwegian government as well as the European commission. The early adoption of ReFuelEU and FuelEU Maritime set ambitious targets for introduction of Sustainable Fuels in aviation and marine transport, aiming for over 31 and 34% respectively by 2040. These targets were then strengthened by the adoption of Renewable Energy Directive III. Nationally, the Norwegian parliament set the ambition of Norway taking a leading role in production of sustainable fuels, followed by the government giving biofuels a significant role in fulfilling increased climate targets for 2030 as part of the so called "Green Book". This includes also increase of blending mandates (Road transport to 33%; Non-road vehicles to 28%; Marine transport to 18%).

With this background, the sending in of an application for establishing a new FME Centre within Sustainable Fuels (SusFuels) was a major milestone, collecting together a consortium of national and international Industries and Research partners in support of facilitating research and development on the deployment of production in Norway.

As we approach the final stages of the Bio4Fuels centre activities, we have an increased focus on dissemination and public awareness, as well as consolidating the activities to ensure highest impact in terms of publications and innovations. This has been realized with continual success in funding from Horizon Europe.

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

Duncan Akporiaye
Centre Leader

Svein Horn
Deputy Centre leader

Summary

The ambition of the Bio4Fuels Centre has been to reduce climate gas emissions from the transport sector, the largest contribution to Norwegian emissions, through sustainable and economic production of biofuels, enabling the basis for production in Norway.
The four main routes addressed by the Centre are:

- Breaking down the biomass to release fermentable sugars 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 syngas, followed by upgrading of the gas to a substitute biofuel.

In addition to the main routes from biomass to biofuels, the research in Bio4Fuels centre has addressed the conversion of side streams and biproducts from the processes to products of higher value than fuels, helping to contribute to the overall economics of the commercial process.

A major focus of research activities in Bio4Fuels has been related to all aspects of sustainability along the value chain, including the economics of the main process steps. Specific topics in this area have been:

- 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.

In addition to the extensive research and innovation activities carried out in the centre, Bio4Fuels established the annual “Bio4Fuels days”, coordinating both national and international contributions within a range of topics relevant for the Centre’s activities. This has included site visits to the key industry partners (Equinor, Biokraft, Norske Skog, Silva Green Fuel, Volvo) in addition to strengthening the collaboration within the Nordic region through arrangement of the Bio4Fuels days conference in Gothenburg.

To support Norway’s international role within the field of Biofuels, the Centre’s partners have been from the start very active in the international arenas, including the IPCC, IEA Bioenergy and ETIP Bioenergy, where major policy relating to solutions for the transport sectors are addressed.

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 seminars, organising webinars and responding to specific topics in the media.
Partners in the Centre have also been extremely well represented in the European funding arena, both as partners and coordinators in the Horizon 2020 and Horizon Europe research program, securing a significant portfolio of EU projects as well as active coordination with other research and industry partners in the EU.

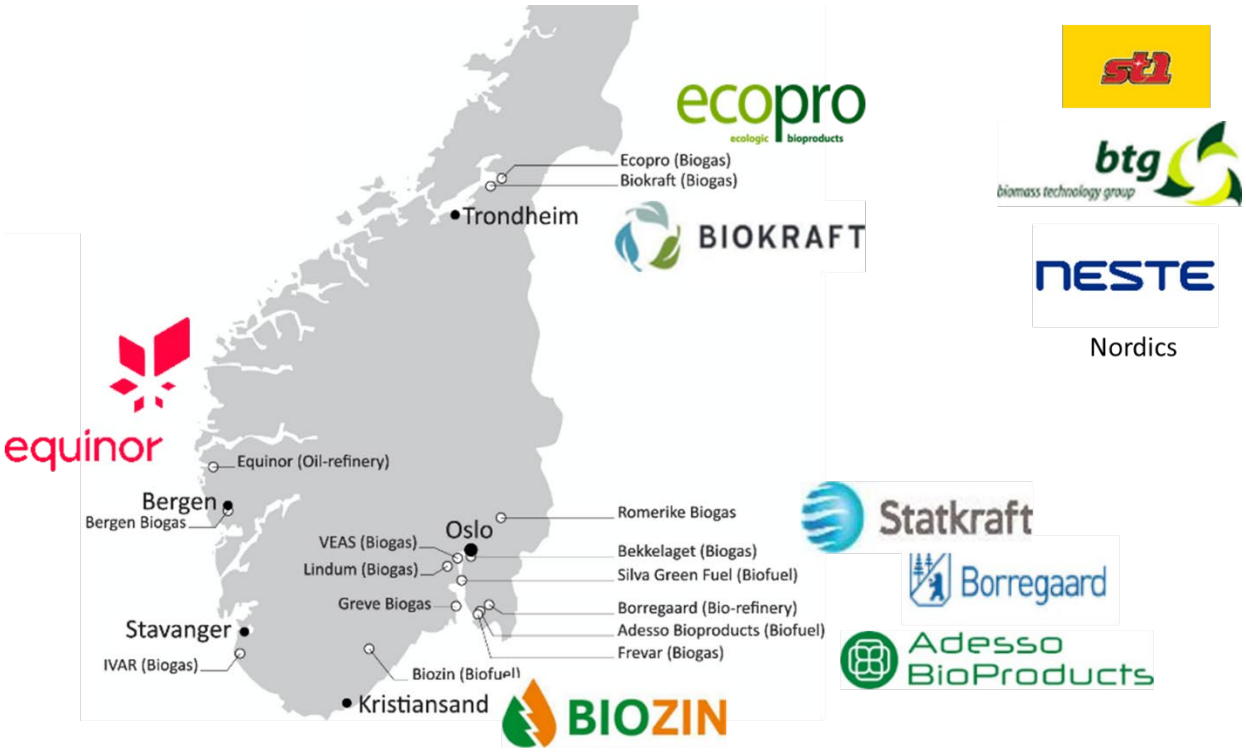
With the recent announcement increased European targets for sustainable fuels in RefuelEU, FuelEU Maritime and RED III, the focus of Bio4Fuels partners is towards removing barriers towards deployment and implementation. This follows-up the Norwegian governments increased role of sustainable fuels in fulfilling more ambitious climate gas reduction targets.

Vision/objectives

The overall vision of the Bio4Fuels FME Centre is to contribute to reduction of climate gas emissions from the transport sector, the largest source of all climate emissions in Norway. This is to be achieved through coordinated research efforts to establish the basis for sustainable routes to production of advanced biofuels in Norway.

The main goal of activities in Bio4Fuels centre is to develop innovative technologies and solutions and support industries to realize economic and sustainable conversion of lignocellulosic biomass and organic residues to transportation fuels, along with added value chemicals. This is based on the following objectives:

- Establishing a framework for producing advanced biofuels and bioenergy from renewable Norwegian resources, thereby enabling a reduced CO_2 footprint
- Identifying the most sustainable value chains, bringing at least two of them to pilot stage
- Achieving up to 20% increase of overall product yield and up to 30% reduced processing costs within the main value chains compared to the current state of the art
- Integrating research fields to develop at least one new conversion technology and at least three processes for value added products within a biorefinery setting
- Strengthen the long term National and international cooperation generating additional projects



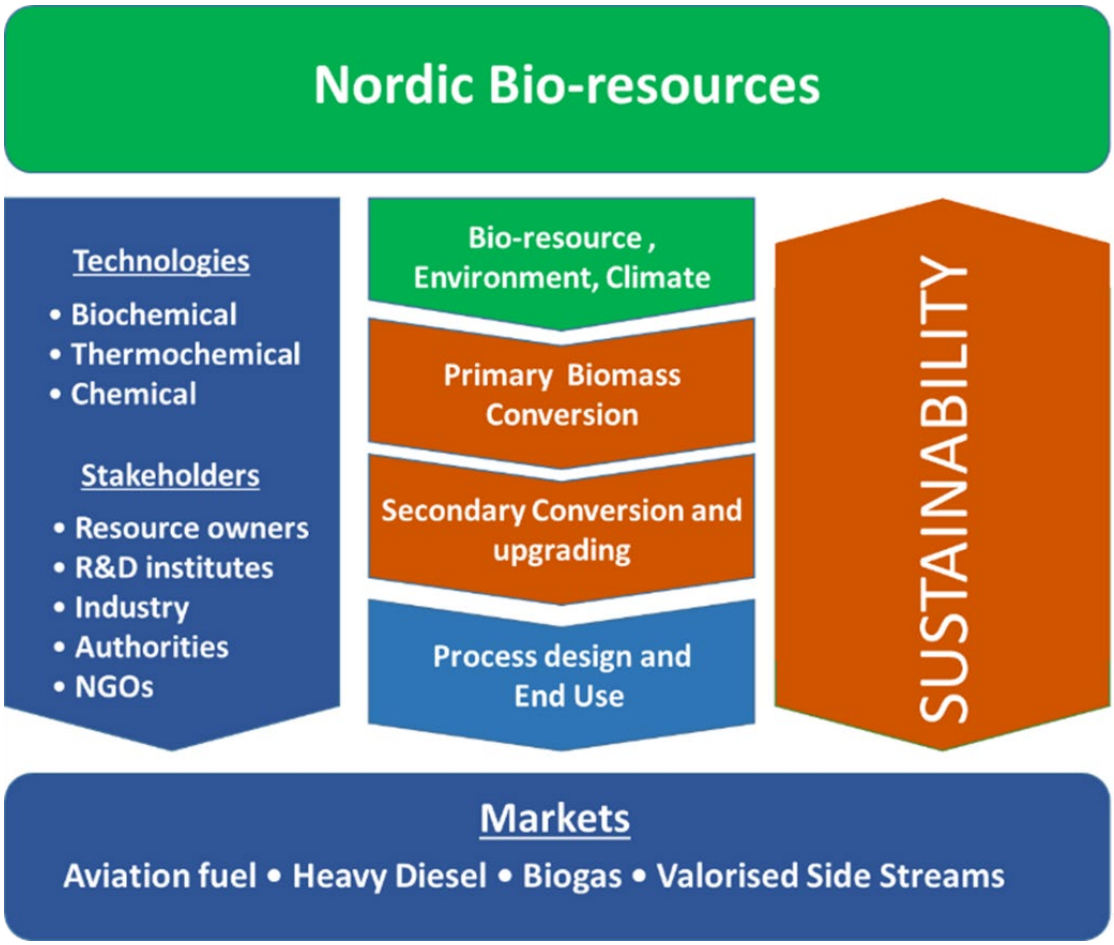
Landscape for potential production of Advanced Biofuels in Norway.

Research plan/strategy

Strategy

The central strategy of the Bio4Fuels centre has been to focus on the overall "value chain" needed to realise the commercial production of advanced biofuels and related products in Norway in particular, and Europe in general. This approach targets key steps in this value chain in terms of research and innovation on the specific challenges and bottlenecks. As shown in the figure below, the research activities address:

- All issues related to the access and use of bio-based feedstocks.
- The main technological routes for converting solid bio-based feedstocks to viable transport fuels.
- The economics of designing and realising a full process and the compatibility with engine motors
- Evaluating and reviewing all environmental and climate aspects of advanced biofuels value chains.

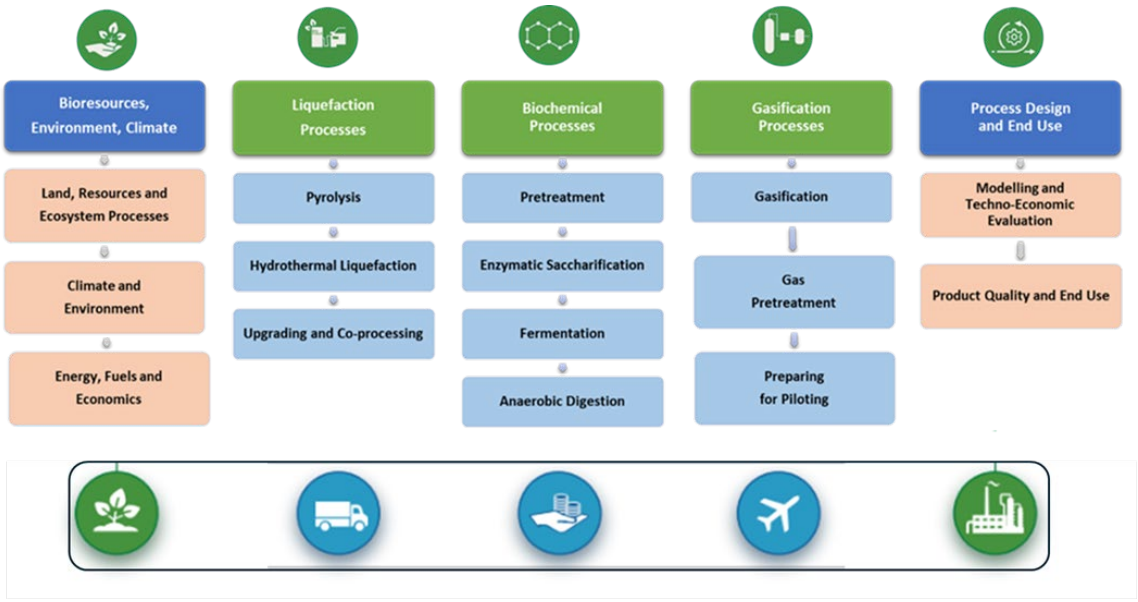


Research Plan

The research plans for the Centre have been developed in relation to the main challenges and bottlenecks of the major technological pathways for the growing advanced biofuels industries. As shown in the figure below, the research activities are structured along major sub-projects, categorised according to

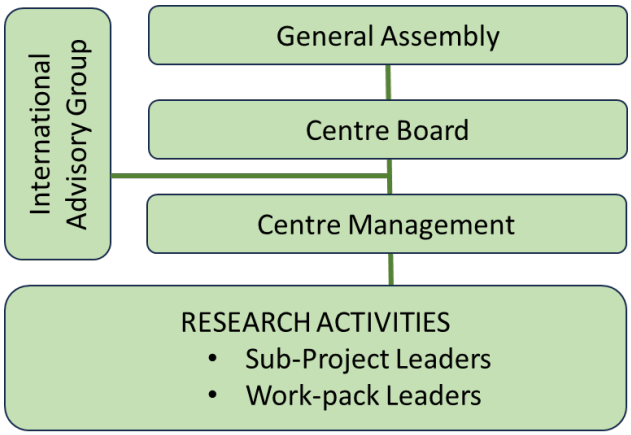
- Technologies for the three major production routes to advanced biofuels
    - Liquefaction processes
    - Biochemical Processes
    - Gasification Processes
- Activities on the wider potential and impact of implementation of production of advanced biofuels
    - Bio-resources, Environment and Climate
    - Process design and use.

The work packages within the sub-projects are aligned with addressing the specific challenges within the Sub-projects, including innovation and optimisation of key process steps, accumulation of knowledge and analysis for assessment of environmental and climatic impacts; and evaluation of the potential economics of different value chains to support research strategies.
The structuring of the research activities ensures that detailed research plans are aligned with the interests of the stakeholders as well as aligned with the European and International research agendas and policies.



Organisation

The overall organisation and governance of the activities in FME Bio4Fuels is shown in the figure below.



Centre Board

	Name	Company/ Institution	Representing
	Klaus Schöffel	Silva Green Fuel (Statkraft)	Technology Partners
	Per Skorge	Norges skogeierforbund	Resource Partners
	Kjell Moljord	Equinor	End Users
	Andreas Lillebø	CAMBI	Technology Partners
	Petter Røkke	SINTEF Energy	Centre Leader Institute
	Hans Fredrik Hoen	NMBU	Host Institute
	Terese Løvås	NTNU	R&D Partner
	Thomas Hartnik	NIBIO	R&D partner*
	*Per Arne Karlsen*	*Research Council of Norway*	*Observer*

*) Alternating every second year with RISE-Pfi, Ife and NIBIO.

Partners

Research partners in Norway:

NMBU, The Norwegian University of Life Sciences
SINTEF, Applied research, technology and innov.
NTNU, The Norwegian Univ. for Science and Technol.
NIBIO, The Norwegian Institute of Bioeconomy
IFE, Institute for Energy Technology
RISE-PFI, Res. Inst. of Sweden & Paper and Fiber Inst.
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
HyperthermicsEnergy 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
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
Biofuel distributors and end users	**Main interest**
St1 Norge as	Bioethanol production and distribution in Norway
Avinor	BioJetFuels for Norwegian airports
Government and State Partners	**Main interest**
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

Highlights from Bio4Fuels' Partners

The Norwegian Environment Agency

New biofuels mandates

During 2023 the Norwegian government determined to implement two new biofuels mandates: marine and off-road. The new mandates are in addition to the two already existing ones for road traffic and aviation.

The newest biofuel mandate was in the marine sector, which was imposed the 1st of October 2023. This mandate dictates that the annual volume of fuels sold to marine purposes must contain 6% biofuels (Annex IX part A or B). The off-road mandate is also known as "other purposes". This mandate was imposed from January 1st 2023 and requires that 10% of fuels sold to other purposes than road, aviation and marine must be advanced biofuels.

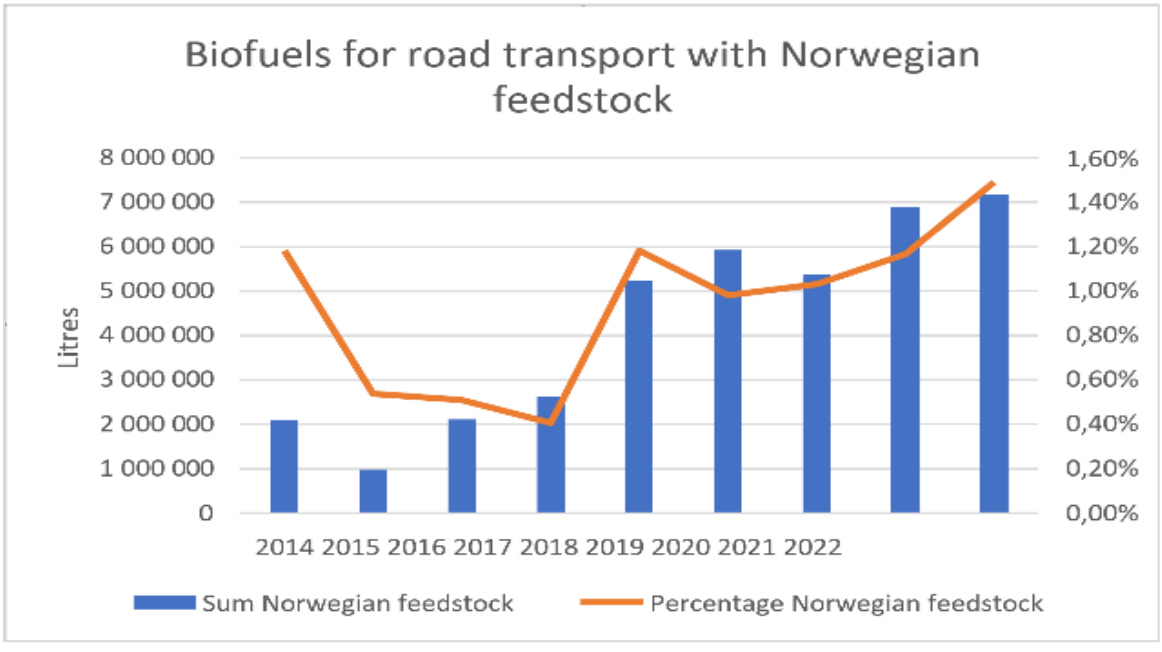
With these new mandates, most fuels used for transportation purposes in Norway is subject to biofuel sales obligations.

Strengthened work to ensure compliance

Additional mandates require more work for the Norwegian Environment Agency, and during 2023 the Agency strengthened the work to ensure compliance with biofuel regulations quite a bit. This happened both by recruiting new resources in the team, and by increasing the focus on surveillance, supervision, and compliance.

Most of the biofuels used in Norway is Annex IX part B, following the definitions from EUs renewable energy directive. The only mandate which opens for the use of conventional biofuels, made from food and feedstocks, is the road mandate. Advanced feedstocks from part B are at particularly risk of fraud, while the use of conventional feedstock has a risk of causing indirect land-use changes, underlining the need for increased surveillance work.

Feedstock from Norway remains low



Both the volume and the share biofuels of feedstock from Norway remains low. After an increase in residual waste from forest operations from 2014 to 2019 it has since dropped to zero. The slight

increase in volume comes mainly from Annex IX part B feedstock such as animal fats, used cooking oil and brown grease.

A look to the future

The Norwegian Environment Agency recommends that the biofuels mandates incentivise the use of Annex IX part A feedstocks, which has better global sustainability properties and could incentivise the production of technologically underdeveloped feedstocks. The level of the biofuel mandates and sub mandates for specific types of feedstocks, are, however, decided by the Norwegian parliament. Lastly, RefuelEU Aviation and FuelEU Maritime are EU legislations which could have implications for the use of biofuels in Norway. Both RefuelEU and FuelEU allow for the usage of other fuels, such as ammonia and hydrogen, or for ships, land-based electricity. As such, the regulations might contribute to increase the demand for other alternative fuels and reduce Norway's dependence on biofuels to cut emissions.

Johnson Matthey: Leading the Energy Transition

Johnson Matthey (JM), a leader in sustainable technologies, has been instrumental in transforming the chemical and energy sectors approach to cleaner and more sustainable processes. In line with the UN's Sustainable Development Goals, its strategy is focussed on four essential transitions to forge a more sustainable global future: switching energy systems, greening chemical production, curbing transport emissions, and advancing a circular economy.
JM's expertise includes the development of sustainable fuel technologies, crucial for reducing emissions in aviation, marine, and energy sectors. It works to create innovative biofuels, e-kerosene, Power-to-X fuels (like e-methanol and e-ammonia) and has made strides in the development of Sustainable Aviation Fuels (SAF). Indeed, JM has secured six licences for SAF production (three in Europe and three in the USA) and its expertise helped make possible the first drop-in 100% SAF transatlantic flight by a commercial airline, completed by Virgin Atlantic in November 2023.
JM is the world's leading methanol technology and catalyst supplier, spearheading low-carbon methanol technology deployment, combining the most efficient and reliable flow sheets in the market with superior catalysts. Its eMERALD™ sustainable methanol process has been optimised to achieve close to 100% hydrogen and carbon conversion. This enables efficient use of feedstocks like agricultural waste, crop residues and municipal solid waste (MSW) to produce bio-methanol- whilst minimising the overall energy requirements and operating costs.

Partnering with global energy leaders

JM's HyCOgen™ technology and its FT CANS™ technologies, co-developed with bp, contribute to renewable diesel and SAF production. These technologies were chosen for a new synthetic fuels plant in Bilbao, Spain, with Repsol and Aramco. JM's partnership with Equinor, a Norwegian energy leader, on the H2H Saltend project—a substantial low-carbon hydrogen plant—further underscores its dedication to sustainable energy. This collaboration combines JM technology with Equinor's energy expertise and is a significant step forward in achieving environmental conservation and sustainable development goals.

Cooperation between the Bio4Fuels Centre's partners

Strategic cooperation

The organization and activities of the Bio4Fuels Centre have been defined so as to maximize the extent of cooperation between partners, both within and external to the centre.
At the highest level to facilitate innovation, interactions between research partners and stakeholders and between stakeholders has been encouraged through the focus on the "value chain" needed for realisation of commercial production of biofuels and related products in Norway. As shown in Figure 1 the main interests of the Stakeholders have been aligned with common challenges to be addressed in the high-level value chain, allowing facilitating input to research plans as well as developing strategic initiatives on behalf of the whole sector. This cooperation has allowed the Bio4Fuels to participate in national and European debate and discussions and provide input to national and European policy initiatives and represent National interests in international arenas. This has been especially important in relation to bioresources and climate related issues, which has seen close cooperation between researchers at NMBU and NTNU and interactions with governmental stakeholders such the Norwegian Environmental Agency and industrial partners such as Silva Green Fuels and Equinor. This has included organisation of a range of webinars, organisation of workshop at Arendalsuka, meetings with the Norwegian Department of Oil and Energy, as well as input to new strategy of the ETIP Bioenergy (European Technology and Innovation Platform for Bioenergy).

Bioresource owners	Main interest
The Norwegian Farmers Union	Biogas production from agricultural feedstocks
The Norwegian Forest Owners' Federation	Value from forest biomass
Ragn Cells AS	Value from organic waste
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
Hyperthermix AS	High temperature biogas production from waste biomass
Norse Biotech AS	Consultancy on biofuels production plants
Zeg Power AS	Electricity and hydrogen production from hydrocarbons
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
Haldor Topsøe (DK)	Chemical/catalytic processes for several bio feedstocks
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
Perstorp Bioproducts AB (SE)	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
Solenis Norway AS	Industry chemicals from woody biomass
Neste (FI)	Biorefinery
Alginor ASA	Seaweed products from a multifunctional biorefinery
Biofuels distributors and end users	**Main interest**
Eco1 as	Biodiesel and biooil distribution in Norway
St1 Norge as	Bioethanol production and distribution in Norway
Preem (SE)	Biofuels production and distribution in Sweden/Norway
Volvo Group Trucks Technology (SE)	Truck engines powered by biofuels
Avinor	BioJetFuels for Norwegian airports
Government and State Partners	**Main interest**
Østfold Fylkeskommune	Sustainability, Resource Use, Transport policy, Technical Economics
Hedmark Fylkeskommune	Sustainability, Resource Use, Transport policy, Technical Economics
Akershus Fylkeskommune	Sustainability, Resource Use, Transport policy, Technical Economics
Oppland Fylkeskommune	Sustainability, Resource Use, Transport policy, Technical Economics
Trøndelag Fylkeskommune	Sustainability, Resource Use, Transport policy, Technical Economics
Follorådet	Sustainability, Resource Use, Transport policy, Technical Economics
Miljødirektoratet	Sustainability, Resource Use, Transport policy
Statens Vegvesen	Sustainability, Resource Use, Transport policy, Technical Economics
NVE	Sustainability, Resource Use, Transport policy, Technical Economics
Innovasjon Norge	Sustainability, Resource Use, Transport policy, Technical Economics

Scientific cooperation

Extensive cooperation between the research partners is facilitated by alignment of the research activities along the three main value chains of special relevance to Norway.
At the Sub-project level, partners with both technical and non-technical interests address common challenges related to the specific value chain including assessment of sustainability and overall economics. At the work package level, representing research on a specific technology or process step, in which user partners with specific interests in the technologies are closely involved with the

research partners in guiding and participating in the research activities. At this level, there has been a high potential for innovation, which as shown in the figure below, has been documented and presented to the industrial stakeholders in dedicated meeting. The close interaction with industry has also resulted in the spin-off of directly funded industrial research projects making use of the expertise developed by the scientists. The cooperation between research partners has been documented in range of common authored publications, including the latest extensive analysis of the economics of the biochemical value chain ("Computer Aided Chemical Engineering Soft modelling of spruce conversion into bio-oil through pyrolysis – Note I: steam explosion and LPMO-activated enzymatic saccharification", Computer Aided Chemical Engineering Volume 52, 2023, Pages 757-762)

Figure showing overview of selected innovations from work packages presented to stakeholders.

WP1.2
- Novel methods and approaches for sustainability analysis in the context of the SDGs

WP2.1
- New technology for coproduction of biocrude, biocarbon and biogas
- Novel two-step pyrolysis technology

WP2.2
- Predictive modelling of inorganics for scale-up

WP2.2/2.3
- "In-situ" upgrading of HTL liquids

WP3.1
- Develop a two-stage fractionation process
- Develop thermoformed products with organosolv lignin

WP3.2
- Identification of enzymes crucial for efficient softwood biomass processing
- More efficient process designs, reaching lower process costs

WP3.3
- Consolidated bioprocessing of lignocellulose materials into fungal lipids

WP3.4
- Result-New (side stream) substrate

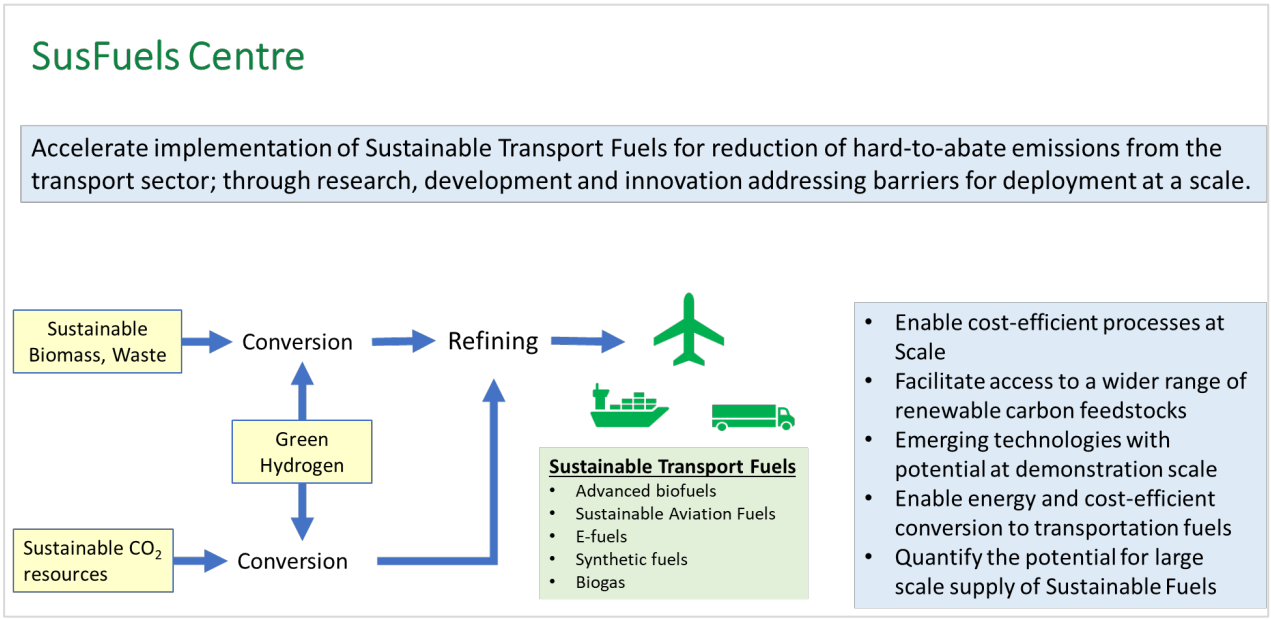
WP4.1
- New gasification plant technology and integrated solution for selected industry cluster site

WP4.3
- Process solutions to biofuel processes
- CFD and system models for the thermal conversion gasification reactors

WP5.1
- Integration of Process Modelling and TEA

WP5.2
- Improved visualization of combustion

At a strategic level, all Bio4Fuels research partners were involved in developing a common initiative towards additional funding of research infrastructure in the Norwegian INFRA program and collaborated extensively in the development and application for a new FME Centre "SusFuels"; as shown below, the ambition is to apply the accumulated expertise from Bio4Fuels to the wider field of sustainable fuels.

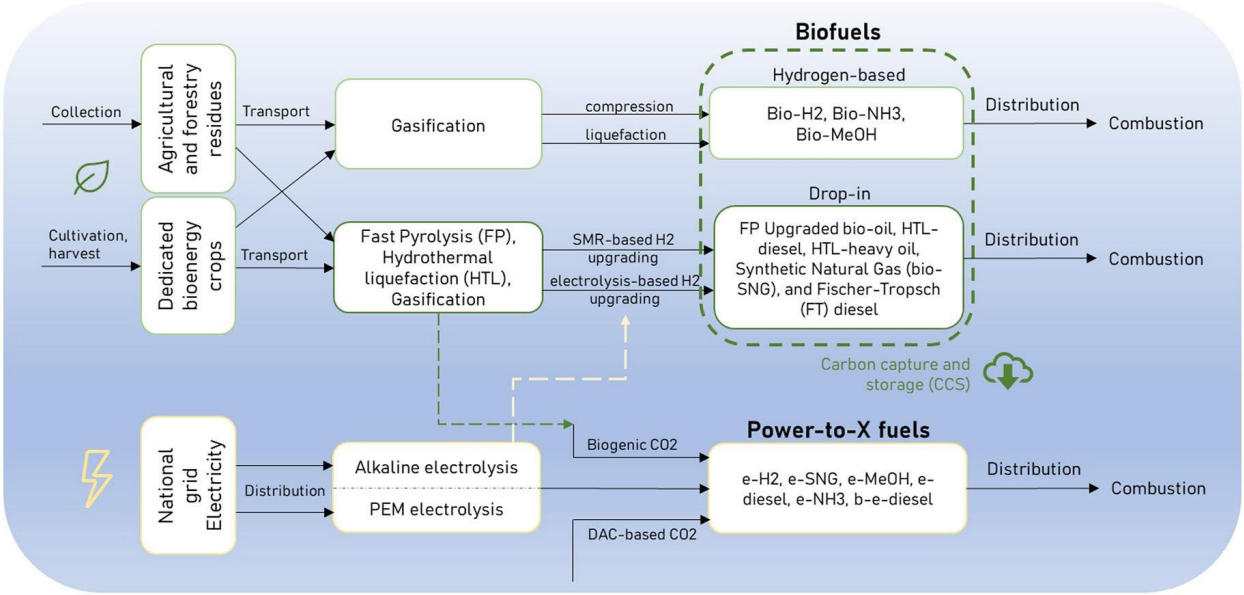


Scientific activities and results

In 2023, Bio4Fuels has contributed to a variety of publications that truly showcase the breadth of activities within the center (see examples of articles below). All value chains have published articles, and several models have been developed based on the technological advancements within the center. The use of biofuels in engines has also been investigated. All of this demonstrates significant collaboration across the center. Furthermore, the work highlights that different types of renewable energy are not in competition, and that we need all forms of renewable contributions to achieve climate goals.

1) Power-to-X fuels and advanced biofuels for the European maritime transport

Key findings include: PtX fuels can achieve lower greenhouse gas intensities than fossil fuels, but only in countries with electricity mix carbon intensity below 100 $gCO_2eq\ kWh^{-1}$. To meet ambitious goals, PtX should be connected to electricity sources below 17 $gCO_2eq\ kWh^{-1}$, achievable with large-scale renewable energy deployment by 2050. Biomass residues are more effective than energy crops in reducing emissions for drop-in and hydrogen-based biofuels. Europe's renewable and low-carbon fuels can supply 32-149% of current annual maritime fuel consumption.



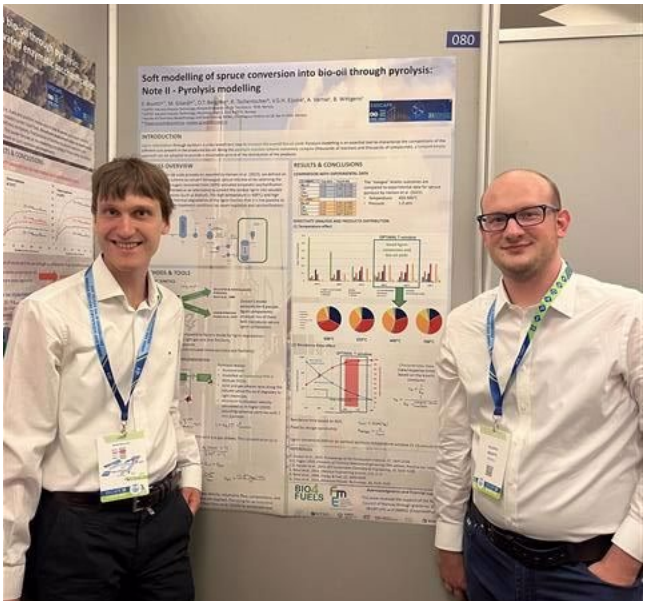
Simplified scheme and system boundaries of Biofuels and PtX conversion routes for deep-sea maritime applications

Reference:
Watanabe, M. D. et al. (2023). Climate change mitigation potentials of on grid-connected Power-to-X fuels and advanced biofuels for the European maritime transport. Energy Conversion and Management: X, 20, 100418. https://doi.org/10.1016/j.ecmx.2023.100418

2) Soft modelling of spruce conversion into bio-oil through pyrolysis

Biorefineries convert biomass into energy and valuable bioproducts, including bio-oil. Combining power and fuel generation is attractive for energy transition and reducing non-biogenic CO2

emissions. Reliable models are crucial for scaling up and designing these complex processes. The proposed soft model accurately predicts experimental data for the key process steps steam explosion and enzymatic saccharification, essential for efficient bio-oil production from lignin-rich biomass. Pyrolysis, a crucial biorefinery step, transforms lignin and residual cellulose into a product mixture. Our merged kinetic model simplifies this complex process, providing a quantitative characterization of main product classes (aldehydes, acids, phenols, furans). It's a versatile tool for scaling up pyrolysis reactors in softwood-based biorefineries This approach is versatile and applicable to various biomass types.



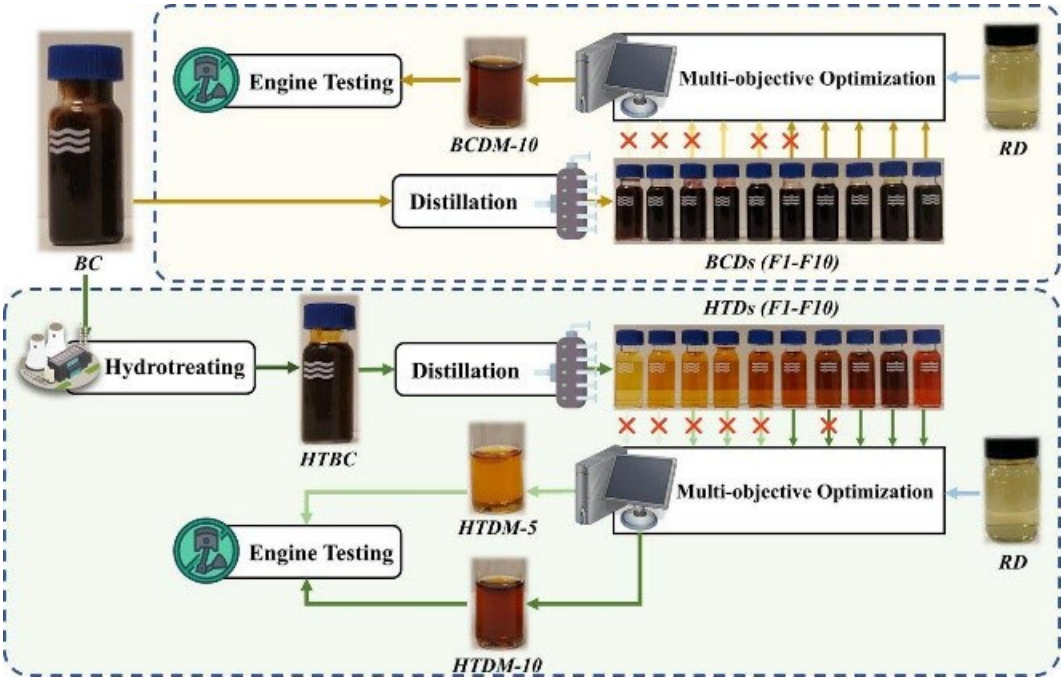
Researchers Matteo Gilardi (left) and Filippo Bisotti (right) from SINTEF represented Bio4Fuels at the 33rdEuropean Symposium on Computer-aided Process Engineering (ESCAPE) in June, 2023.

References:

- *Gilardi, M. et al.: (2023). Soft modelling of spruce conversion into bio-oil through pyrolysis–Note I: steam explosion and LPMO-activated enzymatic saccharification. In Computer Aided Chemical Engineering (Vol. 52, pp. 757-762). Elsevier. https://doi.org/10.1016/B978-0-443-15274-0.50121-9*
- *Bisotti, F. et al.: (2023). Soft modelling of spruce conversion into bio-oil through pyrolysis–Note II: pyrolysis. In Computer Aided Chemical Engineering (Vol. 52, pp. 769-774). Elsevier. https://doi.org/10.1016/B978-0-443-15274-0.50123-2*

3) Hydrothermal Liquefaction (HTL) Biofuel: A Combustion and Emissions Study

This study investigated municipal solid waste (MSW)-based biofuel for use as a diesel blendstock in compression ignition (CI) engines. The biofuel was produced via Hydrothermal Liquefaction (HTL). Two types of tested biofuels—nonupgraded HTL and upgraded HTL—were compared. The study explored combustion characteristics, emissions, and blending with a reference diesel. Overall, HTL blends closely resembled diesel, with upgraded HTL outperforming nonupgraded blends in both combustion and emissions.



Schematic summary from biomass to combustible blend diesel (BC: Bio Crude)

Reference:

Khare, S. et al.: (2023). New Renewable Hydrothermal Liquefaction (HTL) Biofuel: A Combustion and Emissions Study in an Optical Engine. Energies, 16(18), 6754. https://doi.org/10.3390/en16186754

International cooperation

International Arenas and partners

Bio4Fuels partners are actively involved in many of the international arenas for coordinating and developing strategies within bioenergy, biofuels and sustainable fuels. As shown in the table below, scientists from the consortium are active in the major international arenas of IPCC, IPBES and IEA Bioenergy. In addition, research and partners are actively involved in the key European arenas of ETIP, EERA Bioenergy, CBE and CINEA. In addition to these arenas, the Centre consortium has established cooperation with DLR and NEN with respect to certification and standardisation of sustainable fuels as well as active cooperation with a range of Nordic and European research institutes and universities.

European
• Nordic Energy Research • European Technology and Innovation Platform (ETIP) Bioenergy • Politecnico di Torino (Italy) • CINEA Bioenergy Cluster • European Energy Research Alliance (EERA) • Bio-based Industry Consortium (BIC) • Processes4Planet Private Public partnership in Horizon Europe • Supergen Bioenergy Hub
International
• IEA Bioenergy • International Maritime Organisation (IMO) • International Civil Aviation Organization (ICAO) • Intergovernmental Panel on Climate Change (IPCC) • Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)

EU projects

The most extensive international research cooperation is with the large European network of research and industry partners that the Bio4Fuels consortium has established both in Horizon 2020 and in Horizon Europe. The increasing focus on high TRL activities by the European commission has allowed Bio4Fuels partners to secure Innovation projects demonstrating processes along the value chains at the pilot level. An overview of current active EU projects is given in the Table and the impact of the volume of research being carried out in these projects is illustrated in the total financing received by the projects from the European commission.

Figure: Overview of the impact of Bio4Fuels towards R&D partners involvement in EU projects (Total budget of projects in MNOK).

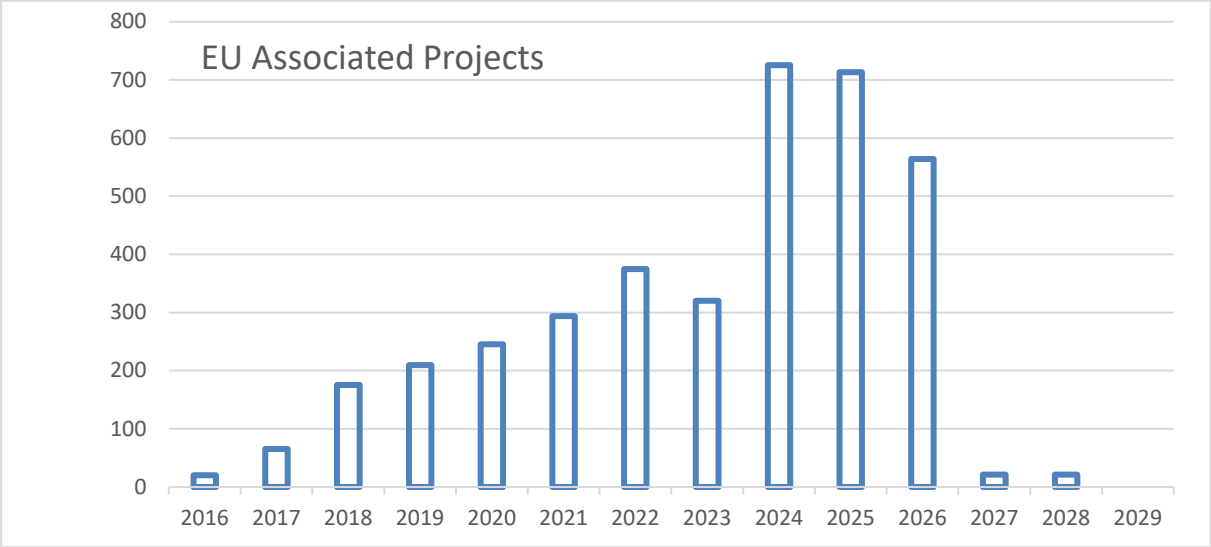


Table: Overview of active associated projects

Project	Project owner	Financed by	Total budget [mNOK]	Short Description of Project
GreenPolymers	NTNU (Indecol)	EEA	8	Novel high-performance polymers from lignocellulosic feedstock
PERFECOAT	SINTEF Industry	BBI-JU	50	New bio-based industrial coating ingredients
EnXylaScope	SINTEF Industry	EU - H2020	60	New enzyme systems for xylan conversion into consumer products
PyroCO2	SINTEF Industry	EU - H2020-GD	440	Demonstration of scalability of chemicals and materials production from CO2 using biotech-based CCU route
FUEL-UP	SINTEF Industry	EU - Horizon	84	Production of advanced bioFUELS via pyrolysis and UPgrading of 100% biogenic residues for aviation and marine sector, including full valorisation of side streams
Valuable	SINTEF Industry	EU - Horizon	69	Producton of Microbial oils form residues of biochemcial processes
Valuable	NMBU	EU - Horizon	69	Producton of Microbial oils form residues of biochemcial processes
HYield	SINTEF Industry	EU - Horizon	1143	Production and purificaiton of hyrogen from gasificaiton of MSW
ELOXYCHEM	SINTEF Industry	EU - Horizon	106	COnvresion of aromatics to carboxylic acids
SEMPRE-BIO	SINTEF Industry	EU - H2020	99	Production of Bio-Methan
EHLCATHOL	NTNU	EU	40	Chemical Transformation of Enzymatic Hydrolysis Ligning (EHL) with Catalytic Solvolysis to Fuel Commodities under mild Conditions
BL2F	SINTEF Energy	EU - H2020	50	Biofuels from black liquor via HTL
SET4Bio	SINTEF Energy	EU - H2020	10,4	Supporting the implementation of the SET Plan Action 8
TULIPS	SINTEF Energy	EU - H2020	325	DemonsTrating lower pollUting soLutions for sustaInable airPorts acrosS Europe // multiple technologies; for Bio4Fuels, SAF is relevant
EBIO	SINTEF Industry	EU	42	Electrochemical upgrading o crude bio liquids
REFOLUTION	SINTEF Industry	HEU	108,5	Production of aviation and marine fuels from biogenic feedstock through intergration with refinery processes
CUBE (ERC Synergy grant) to V.G.H. Eijsink	NMBU	ERC	100	Unravelling the secrets of synthetic and biological Cu-based catalysts for C-H activation

Completed EU Associated projects

Project	Total Budget	Short Description of Project	Bio4Fuels Stakeholders involved
BESTER	26,9	Conversion of lignocellulosic derived sugars to butyrate.	SINTEF Industry
PRO-WOOD	17,5	Understanding microbial lignocellulose breakdown for new wood-protectants.	SINTEF Industry
MetaFluidics	83,2	New enzymes for biomass processing.	SINTEF Industry, NTNU, Novozymes
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
SElectiveLi	5	Conversion of Lignin to value added chemicals.	SINTEF Industry
Pulp&Fuel	49	Studies how renewable fuel production can be integrated to achieve positive synergies for the production of 2nd generation biofuels.	SINTEF, RISE
4Refinery	60	Conversion of lignocellulosic Biomass via HTL and Pyrolysis to Advance Biofuels.	SINTEF Industry
Waste2Road	60	Conversion of Biogenic Waste via HTL and Pyrolysis to Advance Biofuels.	SINTEF Industry, EGE
Baltic Biomass4 Value	30	Enhance capacity of public and private actors within the BSR to produce bioenergy.	
AC2OCem	43	Accelerating Carbon Capture using Oxyfuel Technology in Cement Production.	NTNU (Indecol), Sintef Energy
MarketPlace	8	MarketPlace is aiming at an integrated computing hub for simulations	
DAFIA	58	New conversion routes of municipal solid waste (MSW) and marine rest raw materials (MRRM) to obtain high value products.	SINTEF Industry
NextGenRoadFuels	46	Biofuels from sludge and organic waste via HTL.	SINTEF Energi, Steeper
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
SiEUGreen	70	Resource-efficient urban agriculture for multiple benefits – contribution to the EU-China Urbanisation Partnership	
Oxytrain	30	Research on the mechanism, engineering and application of four different classes of oxygenases	
MicroDE (ERC Starting grant) to P.B. Pope	14	Interpreting the irrecoverable microbiota in digestive ecosystems	
ABC4Soil	4,8	Advanced Biochar Fertilizers for Multiple Ecological Benefits in Soil Conditioning	NTNU, Dr. Kathrin Weber, Prof. Terese Løvås, SINTEF Energy
FunEnzFibres	48	Enzymatic upgrading of cellulosic fibres with LPMOs for the production of textiles and nanocellulose.	NMBU, Borregaard, Novozymes
C1Pro	17,1	Microbial conversion of methanol to value-added products.	NTNU, SINTEF Industry

Active National Associated projects

Project	Total budget [mNOK]	Short Description of Project	Bio4Fuels Stakeholders involved
ACTIVATE	9,8	End use	
Norwegian Seaweed Biorefinery Platform	15	Platform for development of economically and environmentally sustainable biorefinery processes from seaweeds (macroalgae).	SINTEF, NTNU, NMBU
B2A	20	Conversion of biomass to aviation fuels.	NTNU, SINTEF, St1
CSFN	25	Climate Smart Forestry Norway.	NIBIO, NMBU
SLUDGEFFECT	10,5	Life cycle effects from removing hazardous substances in sludge and plastic through thermal treatment.	NTNU
Bio4-7Seas	10,5	Biofuels for climate change mitigation in of deep-sea shipping	NTNU
BioPath	10	Advancing the understanding of regional climate implications of bioenergy systems.	NTNU
SusWoodStove	20	Sustainable wood stoves building integration and value chain optimisation.	NTNU, Sintef Energy
circWood	37.5	Reuse and recycling of wood, resource availability and environmental impacts.	NIBIO, NMBU
InToSludge	0,7	Recover biogas from digestate.	
Foods of Norway (FoN)	218	Centre for Research-based Innovation for biorefining techniques to convert Norwegian bioresources to feed ingredients.	Borregaard
BioSynGas	25	Next generation Biogas production through the Synergetic Integration of Gasification.	NTNU
Low Emission Center	333	Use of ammonia and hydrogen blenads as carbon free fuels in off shore applications.	
Enable	25	Technologies within the energy and transport sector can contribute to a climate friendly transition in Norway.	
BYPROVALUE	10	Production of lipids, chitin/chitosan, glucans and polyphosphate.	Borregaard
OIL4FEED	12	Production of high-value lipids.	Borregaard
SAFE	10	Developing a novel multicomponent microbial biomass as a salmon feed from Nordic woody feedstock.	Borregaard
BYPRPOVALUE	12		
OIL4FEED	12		
LIGNOLIPP	9		
SAFE	10		
FunAccess	13,9	How fungi increase plant cell wall accessibility for complete saccharification and fibre upgrading.	
CAHEMA	10	Use of ammonia and hydrogen blenads as carbon free fuels in ICE for marine transport.	

Recruitment

PhD Student Vedant Pushpahas Ballal (WP1.2); NTNU

Project title: *Environmental sustainability assessment of integrated biofuels/synthetic fuels.*
Ballal is undertaking a techno-economic and environmental assessment of biofuel production in Norway for transport applications. This assessment involves analyzing different pathways to convert Norwegian forestry feedstock to high-quality liquid transportation fuels. The objective of the study is to identify the maximum mitigation potential within the hard-to-abate transportation applications of Aviation, Shipping, and road freight transport, both in the present scenario and future projections.
Supervisor: Francesco Cherubini, NTNU
Start date: 1 September 2022
Planned end date: 31 August 2026

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

This PhD project was 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, I had 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 investigates 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.
Planned Defence: June 2024.

PhD student Zhihui Li (WP2.2), NTNU

Project title: *Co-pyrolysis of biomass and plastic to produce high quality liquid.*
Bio-oil is considered as a potential alternative to traditional energy petroleum, however, bio-oil directly converted from biomass has drawbacks of low heating value, corrosion problems during storage and transfer and instability, because of the high oxygen content (20-60 wt%) in the biomass. Hydrodeoxygenation (HDO) process is one of the most widely used, while upgrading bio-oil by HDO method has a high requirement of plant, and the catalysts for HDO are easily to be deactivated due to the coke formation. In this work, plastic can be considered as a hydrogen donor to achieve in-situ HDO process, by mixing plastic and biomass as the feedstock. At the same time, clay, a very cheap material was applied as an in-situ catalyst during pyrolysis. Modifications were carried out on bentonite and aluminum pillared bentonite clay showing the potential of an alternative to commercial fluid catalytic cracking (FCC) catalyst. Clay catalyzed bio-oil showed low oxygen content (< 10wt%) and high liquid yield (> 60wt%).
Supervisor: De Chen, NTNU
Zhihui Li started as a PhD student in Bio4Fuels in December 2021.
Planned Defense: 2024

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 2024.

PhD student Prajin Joseph (WP3.1), NTNU/RISE-Pfi

Project title: *Organosolv pretreatment of Norway Spruce: Ethanol pretreatment for Biorefinery applications.*
The main objective of the PhD work was to develop and demonstrate in lab-scale an efficient organosolv based fractionation process of Norway spruce to increase the accessibility of cellulose to enzymes and produce high value biopolymers. High purity and low molecular mass organosolv lignin are desirable properties for high value chemicals and products based on organosolv lignin. The results were included in four journal publications and 2 posters presented at international conferences.
Supervisors: Mihaela Tanase Opedal, RISE-Pfi and Størker Moe, NTNU
Prajin Joseph started as a PhD student in 2018 and defended his thesis on 16 December 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 defended 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.
Planned Defense: 24 May 2024.

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.
Planned Defense: 2024

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

Project title: *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.

Planned Defense: 2024.

PhD student Ask Lysne (WP4.2), NTNU

Project title: *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 and defended his PhD degree on 8 March 2024.

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 defended his PhD in February 2022.

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.
Planned Defence: 2024

PhD Student Robert Pujan (WP5.1), NTNU and DBFZ

Project title: *Systematic Modelling of Biorefinery Processes* (Cooperation between NTNU and Deutches Biomasseforschungszentrum).
Modelling based on topologies and ontologies enables reliable and comprehensive model design that always satisfies the conservation principles. Mass and pressure distribution exist on two distinctly different time scales, demanding for a model split into dynamics and event-dynamics. The software tool PreMo is designed on this methodology and thus significantly accelerates the process of custom model design, initiation and simulation.
Supervisor: Heinz Preisig, NTNU
Start: 1 January 2019
End: December 2022 (no defense yet)

Khare Shivang (WP5.2), NTNU

Project title: *Combustion and Emissions Study of New Renewable Hydrothermal Liquefaction (HTL) Biofuel: An Experimental and Numerical Investigations.*
The study involves the investigation of municipal solid waste (MSW) based biofuel to demonstrate its utilization as a diesel blendstock in a compression ignition (CI) engine. The biofuel was produced from the Hydrothermal Liquefaction (HTL) process. The tested biofuels represented both distilled (known as nonupgraded HTL biofuel) and hydrotreated (known as upgraded HTL biofuel) fuels, obtained from raw bio-crude. The effects of the HTL biofuel and diesel blending on the combustion and emission characteristics were investigated. A comparative study of nonupgraded and upgraded HTL biofuel in terms of combustion and emissions was conducted. The experiments were conducted in an optically accessible compression ignition chamber (OACIC) with engine-like thermodynamic conditions. The study also explores the role of fuel nitrogen on Nitrogen Oxides (NO_x) emissions from HTL biofuels by employing a Stochastic Reactor Model (SRM) for detailed analysis.
Supervisor: Terese Løvaas, NTNU.
Start: 3 November 2020
Planned Defense: 2024

Communication and dissemination activities

Bio4Fuels' Open Webinars

We arranged six webinars during 2023, with participants from the whole Centre and beyond:

Theme (with Link to Recording)	Date 2023	Participants
Forest Resources	10 Feb	50
Sustainable Aviation Fuels	27 Apr	51
Novel Applications of Anaerobic Digestion Processes	15 Jun	14
Advanced Biofuels and the EU Directives	24 Aug	31
Updates on Anaerobic Digestion – Perspectives from the US	15 Sep	45
Climate-Friendly Energy in the Norwegian Armed Forces and Norwegian Construction Site Engines	23 Nov	21

Centre Status Meetings

The Centre Status Meetings gives an overview of

- the research and administrative status,
- associated projects, and
- Bio4Fuels stakeholders' activities.

Two meetings were held in 2023:

14 March 2023 (Teams)

- Welcome – Duncan Akporiaye, Centre Leader
- Updates form a selection of Bio4Fuels Sub Projects:
    - SP2 – WP2.2 Nikalet Everson, SINTEF Energy: *Stepwise Optimization of HTL Slurry Preparation*.
    - SP3 – WP 3.3 Lu Feng, NIBIO: *Bioaugmentation of enriched hydrogenotrophic methanogens into trickle bed reactors for H_2/CO_2 conversion*.
    - SP4 – WP4.3 Samani Ahmadpour Nastaran, USN: *Eulerian–Lagrangian Simulation of Lignin Gasification Behavior in a High-Temperature Entrained-Flow Reactor*.
- *New FME after Bio4Fuels?* – information by Duncan Akporiaye, Centre Leader
- *The New EU project REFOLUTION* - Silje Håkonsen, SINTEF Industry

14 June 2023 (Teams)

- *Welcome and Information from Bio4Fuels Management* - Duncan Akporiaye, Centre Leader
- *Stakeholder presentation*: Cambi AS, Andreas Lillebø (CTO)
- Updates from two Bio4Fuels Sub Projects:
    - SP5 – WP5.1 *Modular design of unit operation models developed for process Design and Technical economic evaluation*, Matteo Gilardi, SINTEF Industry
    - SP1 – WP1.3 *The location and capacity-dependent price impacts of biofuel production and its effect on the forest industry*, Per Kristian Rørstad, NMBU

Bio4Fuels Days 2023, Scandic Sjølyst, Oslo (15 – 16 November 2023)

15 November:
Bio4Fuels Partner Presentations – Technology Implementation
- *Welcome* by Duncan Akporiaye, SINTEF Industry, Bio4Fuels' Centre Leader
- *Status and perspectives for production and uptake of Sustainable Aviation Fuels*, Arvid Løken, Avinor
- *Locally Produced Sustainable Biofuel*, Anne Marit Post-Melbye, Zero
- *The European biogas industry 2013 – 2033, some reflections halfway*, Håvard Wollan, Biokraft

Bio4Fuels Days 2023 – Continued

Bio4Fuels Sub Projects' Presentations – Technology Status
- *SP1 Bioresources, Environment, Climate,* Francesco Cherubini, NTNU
- *SP2 Liquefaction Processes*, Judit Sandquist, SINTEF Energy
- *SP3 Biochemical Processes*, Aniko Varnai, NMBU

Poster Session with Evaluators:
- Anne Marit Post-Melbye, ZERO
- Ole Jørgen Marvik, Innovasjon Norge
- Jon Hovland, SINTEF
- Svein Horn, NMBU

Prize Winner 2023: PhD Student Zhihui Li, NTNU

Anne Marit Post-Melbye, ZERO, evaluating posters.
Photo: Haldis Watson, SINTEF

16 November:
Bio4Fuels Partners' Meeting
- *Introduction* by Svein Horn, NMBU, Bio4Fuels' Deputy Centre Leader
Bio4Fuels Sub Project Presentations Continues
- *SP4 Gasification Processes*, Morten Seljeskog, SINTEF Energy
- *SP5 Process Design and End Use*, Bernd Wittgens, SINTEF Industry

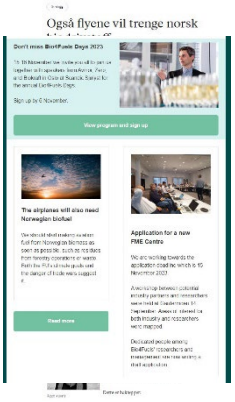
Group Work
- Bio4Fuels Days 2024, Helsinki June '24
  - Work Plans 2024-2025
  - New Associated Projects

Other important meetings

- Bio4Fuels has co-organized a workshop on Biofuels and e-fuels land use and climate effect at NTNU's Energy transition week in March 2023.
- ETIP Bioenergy had three Steering Committee meetings and its 11th Stakeholder Plenary meeting in 2023. In addition we have updated the Strategic Research and Innovation Agenda, which can be downloaded here.
- In the national Bioenergy days (Bioenergidagene) Judit presented the coming EU regulations and their implications for Norway.

Duncan Akporiaye at the ETIP meeting

Newsletters 2023



- 4 newsletters in 2023; Spring, Summer, Autumn, and a Christmas greeting.
- Change of format from pdf attachment to Benchmark Email platform
- The SP and WP-leaders submit news from their research and the Management Team share past and present activities with our members.
- Recent newsletters can also be found on the website.

Arendalsuka 2023

Short-haul and sustainable biofuel: Is it possible?

- Debate on M/S Lofoten + streaming
- The chairman was SINTEF's head of communications, Stein Mortensholm.
- Knowledge base / discussion with industry and environmental organisations
- Participants from NMBU, SINTEF, Silva Green Fuel, Environmental Foundation ZERO, Biozin, and the Norwegian Environment Agency

Opinion piece in Dagens Næringsliv

The airplanes will also need Norwegian biofuel

- Opinion piece in Dagens Næringsliv 12 October
- Written by Duncan Akporiaye and Ågot Åkra with good help from SINTEF journalist Svein Tønseth
- Based on the government's desire to put forward "a plan to increase the production of advanced biofuel in Norway" and Shell's suspension of Biozin's factory project.

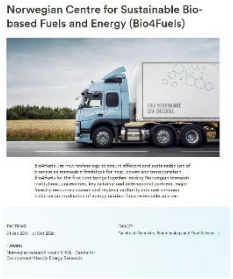
Feature article at Gemini.no

Reply to the "Climate bluff"

- Chronicle on NRK by Bellona, Elektroforeningen (EFO) and
- Bio4Fuels worked on a response when Drivkraft Norge ahead of the game with a good reply.
- We completed our reply which was published on Gemini.no on 8 December 2023.

Website 2023

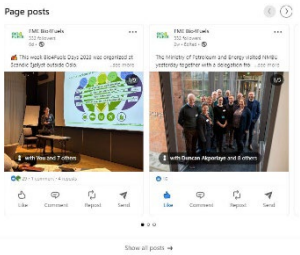
- NMBU are hosts for the Bio4Fuels website.
- New platform launched summer 2023.
- We share newsletters, link to webinars, annual reports, and information about Bio4Fuels and our research and members here.



LinkedIn 2023

@ FME Bio4Fuels

- We share our own news and events as well as those we find relevant for our followers.
- We have 332 followers per 19 Nov 2023
    - up 120 in 2022 and 163 in 2023



Bio4Fuels Industrial and public stakeholders

BIORESOURCE OWNERS

BIOFUEL AND BIOCHEMICAL PRODUCERS

TECH./KNOWLEDGE PROVIDERS, NORWEGIAN

TECH./KNOWLEDGE PROVIDERS, INTERNATIONAL

BIOFUEL DISTRIBUTERS AND END USERS

TRADE ORGANISATIONS

GOVERNMENT AND STATE PARTNERS

Appendix (see attachment):

- Personnel
- Accounts
- Publications