Norwegian Centre for Environmentfriendly Energy Research

Bio4Fuels

Norwegian Centre for Sustainable Bio-Based Fuel and Energy

HIGHLIGHTS FROM 2023

Enabling sustainable biofuels production in Norway

BIO4 FUELS

Contents

Front page illustration: Big pipeline in the abstract refinery. Johnson Matthey

Illustration: The Research Council of Norway

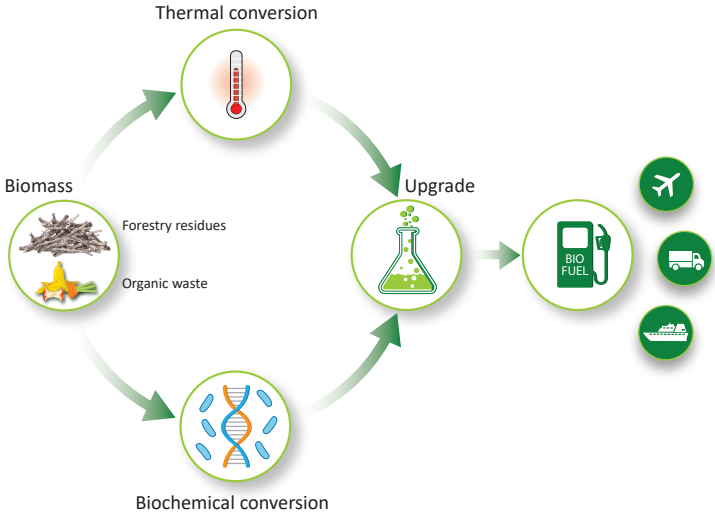
What is Bio4Fuels?

The goal of the FME Centre Bio4Fuels is to contribute to the reduction of climate gas emissions from the transport sector. We aim to enable a sustainable production of biofuels in Norway based on low-grade woody biomass, organic and agricultural waste.

Bio4Fuels also addresses issues related to viable commercial production of advanced biofuels from sustainable biomass. The ambition is to improve the technologies and economics of processes for converting biomass to advanced biofuels, investigate the sustainability and impact of large-scale use of low-grade biomass, and to evaluate and design the process concepts and testing quality of the biofuels for the engines used today.

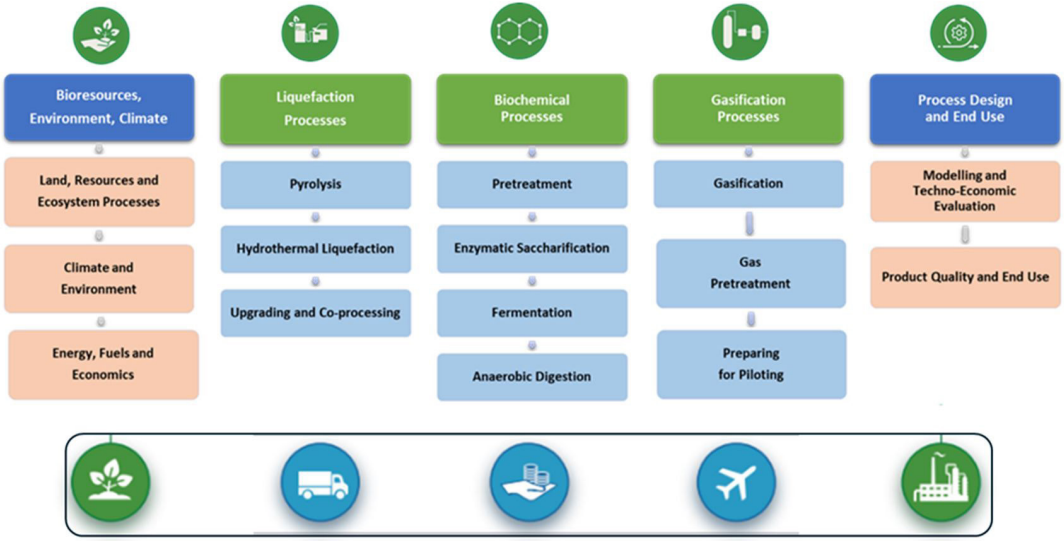
The prospects for advanced biofuel production in Norway have increased significantly through the activities of key stakeholders since the establishment of Bio4Fuels in 2017.

Centre start date: 1 January 2017
Centre end date: 15 October 2025



Value chains and research

From sustainable biomass resources to economic production of advanced biofuels



SP = sub-project

From the Centre Leader and Deputy Centre Leader

In 2023, sustainable transport fuels gained prominence due to significant announcements by the Norwegian government and the European Commission. Initiatives like **ReFuelEU** and **FuelEU Maritime** set ambitious targets for sustainable aviation and marine fuels, aiming for 31% and 34% respectively by 2040. These goals were reinforced by the adoption of **Renewable Energy Directive III**. Nationally, Norway aimed to lead in sustainable fuel production, emphasizing biofuels as part of the "Green Book" to meet increased climate targets for 2030 - an ambition that was addressed by Bio4Fuels in webinars and meetings with the Ministry of Energy.

The Bio4Fuels Centre focuses on reducing climate gas emissions from the transport sector, a significant contributor to Norwegian emissions. Our primary goal is the sustainable and economically viable production of biofuels within Norway.

Duncan Akporiaye, SINTEF
Centre Leader

Svein Jarle Horn, NMBU
Deputy Centre Leader

The Centre addresses four main biomass-to-product routes:

- **Bio-alcohols:** Enzymatic processing of biomass to release fermentable sugars that are converted to alcohols, which can be blended into existing fuels.
- **Biogas:** Fermenting biomass without oxygen to produce biogas, which can be upgraded to methane, liquefied, or converted to hydrogen for transport use.
- **Liquid biooil:** Treating biomass at higher temperatures without oxygen to create liquid biooil, which is then upgraded to relevant biofuels.
- **Syngas:** Treating biomass at higher temperatures to produce syngas, followed by upgrading to substitute biofuels.

Additionally, Bio4Fuels research covers sustainability aspects across the value chain, including process economics. Specific topics include improving technologies, assessing large-scale use of low-grade biomass, and testing biofuel quality for existing engines. Partners actively engage in international forums, addressing transport sector solutions. Bio4Fuels contributes to Norway's energy research landscape and supports the debate on biofuels' role.

We appreciate the ongoing support from Bio4Fuels stakeholders, both industrial and public, and commend the dedication of our research partners.

Some of our partners

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.

Big pipeline in the abstract refinery

The Norwegian Environment Agency

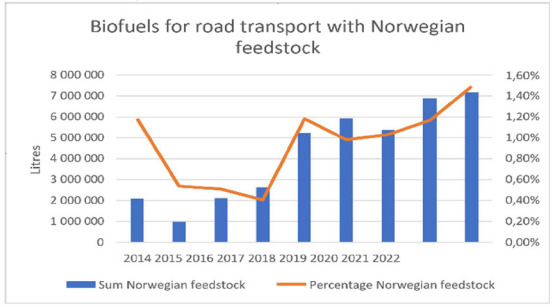
New Biofuels Mandates
In 2023, the Norwegian government introduced two new mandates for biofuels, targeting marine and off-road sectors. These complement the existing mandates for road traffic and aviation. As of October 1, 2023, marine fuels must now include 6% biofuels, following Annex IX part A or B criteria. The off-road sector, encompassing uses other than road, aviation, and marine, has been required since January 1, 2023, to blend 10% advanced biofuels into their fuel mix. With these additions, nearly all transportation fuels in Norway must now meet specific biofuel inclusion rates.

Compliance and Oversight Enhancements
To manage these expanded requirements, the Norwegian Environment Agency has significantly increased its compliance and oversight efforts. This includes new hires and a greater focus on monitoring and enforcement. Most biofuels used in Norway fall under Annex IX part B, but the road transport mandate still allows conventional biofuels derived from food and feed crops, which carry risks of indirect land-use changes.

Feedstock from Norway remains low

Domestic Biofuel Feedstock
The use of domestic biofuel feedstocks remains low, despite previous increases in waste-derived materials from forest operations. The predominant biofuels now come from imported materials like animal fats and used cooking oils.

Future Directions
The agency advocates for mandates that favour Annex IX part A feedstocks, known for better sustainability. The influence of EU's RefuelEU Aviation and FuelEU Maritime regulations could shift focus towards alternative fuels like ammonia, hydrogen, and land-based electricity, potentially diversifying Norway's approach to reducing emissions in transportation.



Increased EU ambitions

Since February of 2023, the EU has increased its ambitions for reduction of climate impact from the transport sector. This builds on the original targets of ReFuelEU, with specified targets for FuelEU Maritime, guidelines for sustainability in RED III, additional increase in ambitions for 2040 and development of an overall strategy for Carbon Management.

References:

ReFuelEU Aviation - https://bit.ly/4bIlcmU
FuelEU maritime initiative - https://bit.ly/4e6Yrun
Renewable Energy Directive - https://bit.ly/3VoOaCp

Equinor Mongstad refinery. Photo: Øyvind Hagen

Bio4Fuels relevant industrial activities in Norway

ADDITIONAL NORDIC INITIATIVES

Reseach activities - Selected highlights

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

Accelerating the large-scale production and use of renewable and low-carbon fuels (RLFs) is recognized as a key factor in achieving the climate mitigation targets set for the international maritime sector throughout the next years. In Europe, a climate neutrality goal by 2050 was recently proposed within the context of the FuelEU Maritime initiative. Key findings in this study 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.

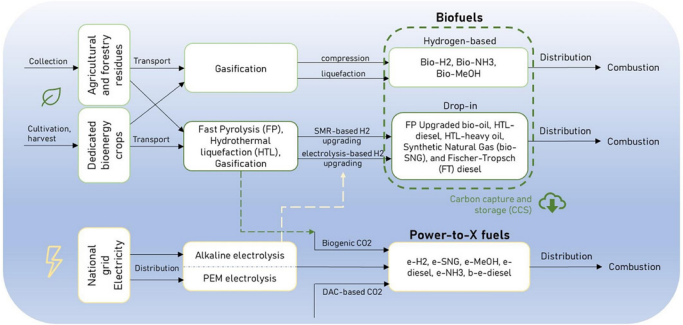


Figure: Simplified scheme and system boundaries of Biofuels and PtX conversion routes for deep-sea maritime applications.

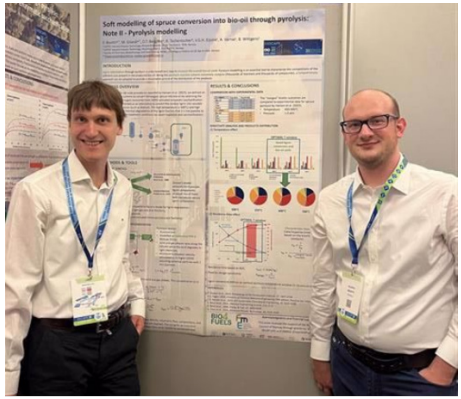
Reference:

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

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 CO_2-emissions. Reliable models are crucial for scaling up and designing these complex processes. This work presents a 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.



Picture: Researchers Matteo Gilardi (left) and Filippo Bisotti (right) from SINTEF represented Bio4Fuels at the 33rd European 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

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

Hydrothermal Liquefaction (HTL) is a thermochemical process that utilizes water at sub, near, or supercritical conditions as the reaction medium to break down and decompose the complex organic molecules present in biomass. This process results in the production of an energy-dense liquid known as bio-crude. 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 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.

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

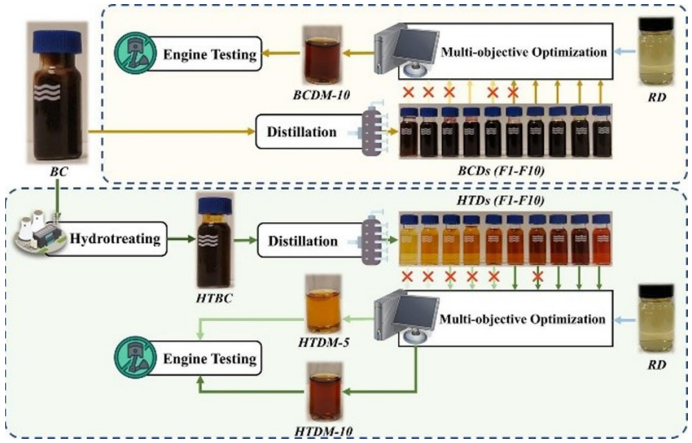


Figure: Schematic summary from biomass to combustible blend diesel (BC: Bio Crude)

Camilla Fløien Angeltveit

Ask Sødahl Lysne

PhD Defence

Shedding light on enzymatic saccharification of cellulose

Camilla Fløien Angeltveit

24 May 2024 Camilla Fløien Angeltveit successfully defended her thesis "Interplay between LPMOs and cellulases during enzymatic degradation of cellulose - effects of time, lignin, light and substrate concentration". The work was performed at the Faculty of Chemistry, Biotechnology and Food Science, NMBU, as part of Bio4Fuels work package 3.2, Enzymatic Saccharification.

Camilla has worked on lowering the cost of biofuels production by optimizing enzyme cocktails and process conditions, with a particular focus on the role of lytic polysaccharide monooxygenases to improve the enzymatic saccharification of lignocellulosic biomass. Making biofuels cheaper and more accessible is essential to enable the complete replacement of fossil fuels, which in turn will have a positive effect on greenhouse gas emissions and the environment.

The thesis aimed to improve our understanding of LPMO-cellulase interaction by manipulating LPMO activity through light-induced H2O2 production from lignin and adjusting parameters like enzyme composition and substrate concentrations to increase the overall saccharification efficiency.

From waste to green flights

Ask Sødahl Lysne

8 March 2024 Ask Sødahl Lysne successfully defended his thesis "Steam reforming of biomass gasification tar impurities with Ni-Co/Mg(Al)O catalysts - Experimental studies using model tar components." The work was performed at the Department of Chemical Engineering, NTNU, as part of Bio4Fuels work package 4.2 Gas Pretreatment.

Future aviation could use renewable carbon sources like biomass (wood, waste) for fuel instead of fossil oil. Biomass gasification breaks down this material at 700-900 °C into a mix of hydrogen and carbon monoxide (synthesis gas) that can be turned into aviation fuel. However, tar in synthesis gas must be removed, either through high-temperature decomposition or catalysts.

Research by Ask S. Lysne has developed nickel-cobalt-based catalysts that boost efficiency by converting tar into more synthesis gas while reducing harmful carbon buildup. This produces cleaner synthesis gas for sustainable aviation fuel, reducing the environmental impact of long-haul flights.

Dr. Lysne is now continuing his work as a Research Scientist at the Department for Thermal Energy, SINTEF Energy Research.

Bio4Fuels days 2023

Bio4Fuels' partners meet once per year during the Bio4Fuels Days. 15-16 November 2023 we met at Scandic Hotel Sjølyst, in Oslo.

Previous years we have met at locations close to one of our stakeholders' plants or refineries, but this year's meeting was without a site visit. Apart for one presentation, the speakers were all present.

The theme for Bio4Fuels Days 2023 was "Technology Implementation and Status". The Centre is in its final years, and we wanted to

- get feedback from our stakeholders on their status and needs, and
- give a bird's eye view on our research achievements so far.

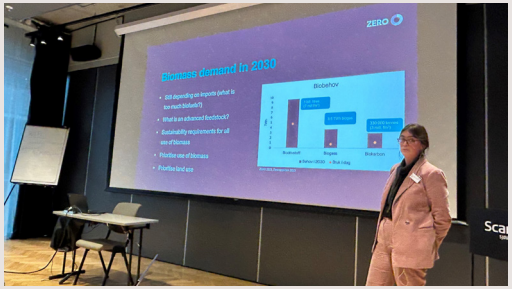
Stakeholders

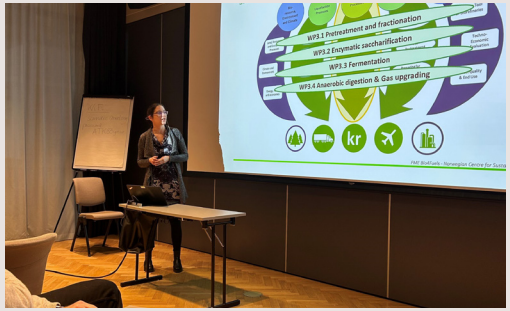
Three central stakeholders gave presentations during Bio4Fuels Days 2023: Avinor, Zero and Biokraft. Avinor gave us their status and perspectives for production and uptake of sustainable aviation fuels. Zero gave an overview of locally produced biofuel - needs and amounts. Biokraft gave us reflections on the European biogas industry.

Bird's eye view from Bio4Fuels sub-projects

Bio4Fuels' five sub-project leaders summed up seven years of research highlights (2017-2023), and reflected upon what we know today, and what we do not yet know. An overview of innovations and future plans were also presented.

Full program: https://om.no/2V89





EU Projects

Bio4Fuels is associated with many EU projects, both completed and ongoing. Here is a brief introduction to two of them.

Icarus

ICARUS is dedicated to advancing Sustainable Aviation Fuel (SAF) production by addressing critical technology limitations in three key routes:

- Biocrude from hydrothermal liquefaction
- Isobutanol from lignocellulosic biomass
- Synthetic Fischer-Tropsch from biomass gasification

The project activities are structured along four scientific work packages (WP) addressing important aspects of framework conditions for SAF development in Europe and Mission Innovation Countries (MIC), innovations in SAF technologies, assessments for cost-effectiveness and sustainability, as well as best practices and concepts for up-scaling of SAF production value chains.

www.icarus-biojet.eu

FuelUp

Production of advanced bioFUELS via pyrolysis and UPgrading of 100% biogenic residues for aviation and marine sector, including full valorisation of side streams.

This project will demonstrate the complete value chain from Nordic biomass to aviation and marine engines through the fast pyrolysis route, with simultaneous valorisation of process side streams. The project supports cost-effective chemical processes that have the potential to de-fossilize the transport industry. Successful implementation will raise the TRL to 7, paving the way for sustainable transportation.

www.fuelup-project.eu

Funded by the European Union

Organisation 2024

Management and leaders

Biochemical Processes — SP3

Aniko Varnai, NMBU
Mihaela Tanase Opedal, RISE PFI
Alexander Wentzel, SINTEF
Lu Feng, NIBIO

SP2 — **Liquefaction Processes**

Judit Sandquist, SINTEF
Kai Toven, RISE PFI
Roman Tschentscher, SINTEF

Gasification Processes — SP4

Morten Seljeskog, SINTEF
Edd Blekkan, NTNU
Marianne Eikeland, USN

SP1 — **Bio-resources, Environment and Climate**

Francesco Cherubini, NTNU
Rasmus Astrup, NIBIO
Per Kristian Rørstad, NMBU

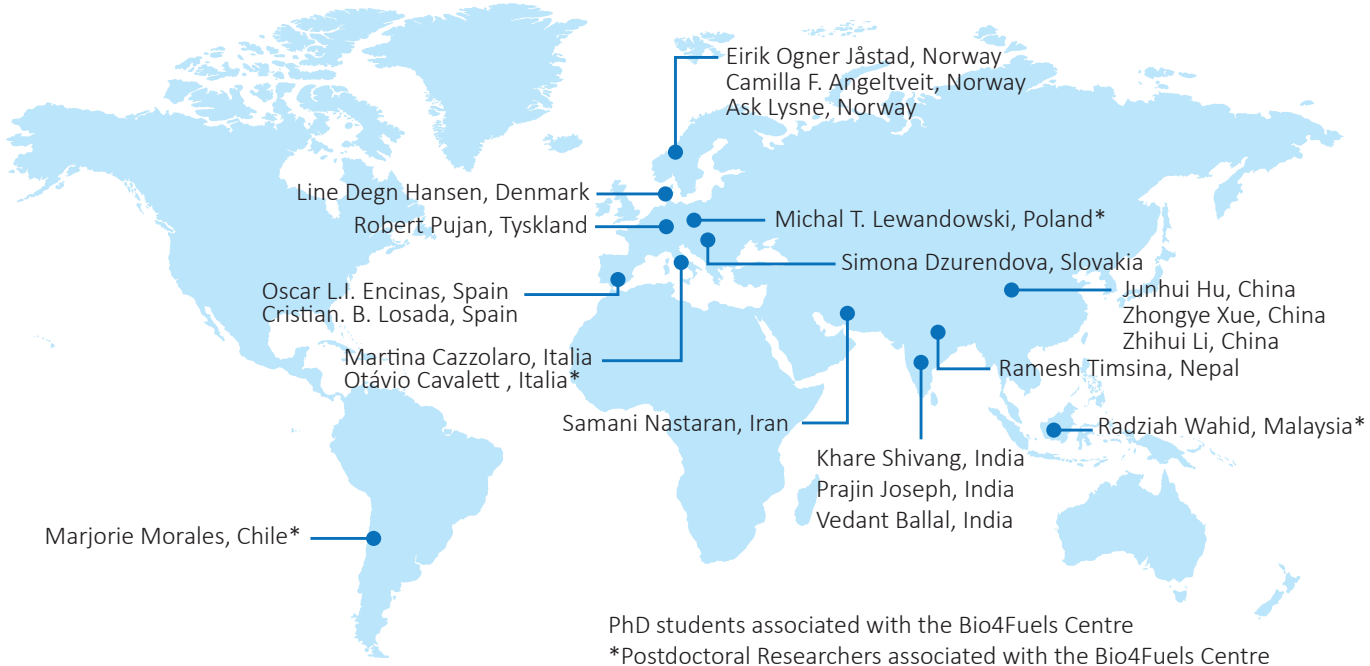
Process Design and End Use — SP5

Bernd Wittgens, SINTEF
Terese Løvås, NTNU

Management and Staff

Duncan Akporiaye, SINTEF
Svein Jarle Horn, NMBU
Janne Beate Utåker, NMBU
Carlos Dinamarca, SINTEF
Ann-Solveig Hofseth, NMBU
Camilla Fløien Angeltveit, NMBU
Haldis Bjerva Watson, SINTEF

PhD students and Post Docs in Bio4Fuels and their country of origin



PhD students associated with the Bio4Fuels Centre
*Postdoctoral Researchers associated with the Bio4Fuels Centre

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

Authors: Duncan Akporiaye, Svein-Jarle Horn, Haldis B. Wotson, Ann-Solveig Hofseth, Carlos Dinamarca, Janne Beate Utåker.
Layout: T. Heggenhougen og Berit Fossum, SINTEF. Courtesy to our stakeholders for photos.