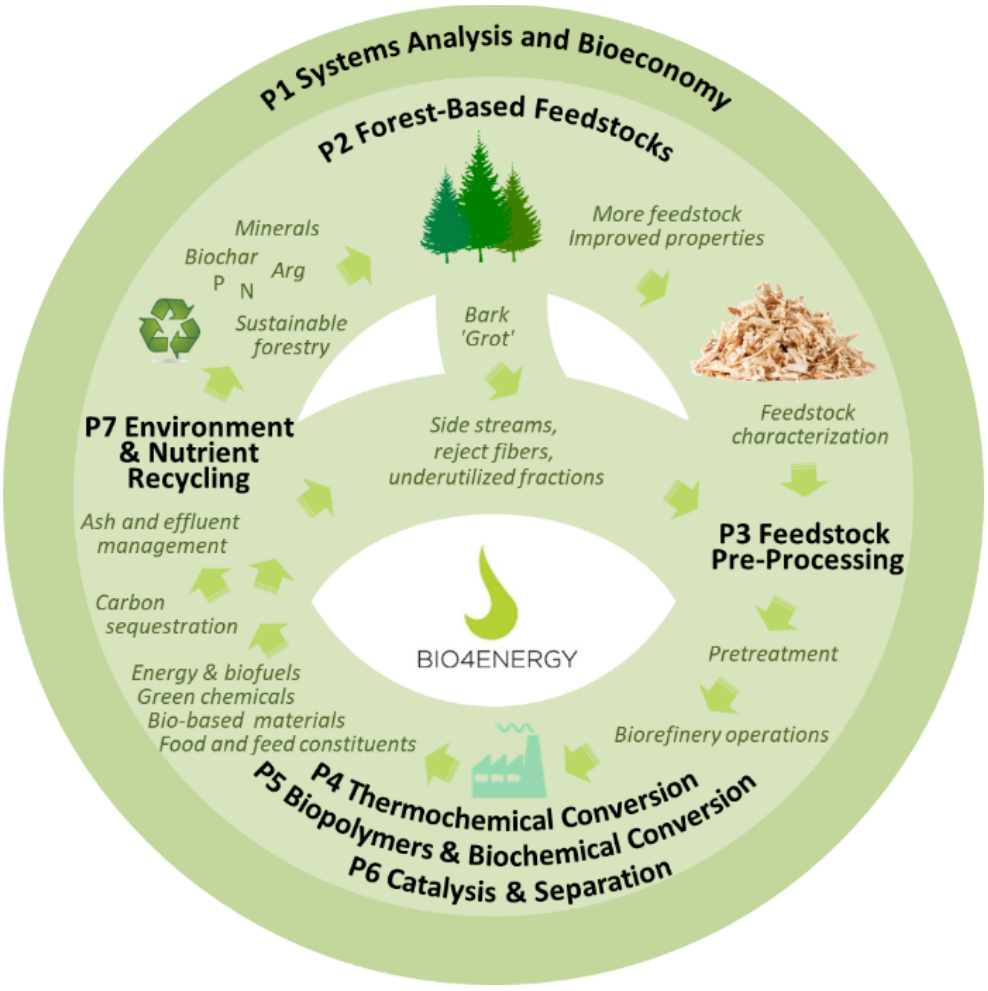
BIO4ENERGY

Annual report 2023



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www.bio4energy.se

Bio4Energy – a strategic research environment

Bio4Energy is a Strategic Research Environment funded through the Swedish Government's investment in high-quality research in 24 strategic research areas. Our research focuses on biorefineries for sustainable production of renewable energy carriers, chemicals and materials.

Partners are Umeå University (UMU), Luleå University of Technology (LTU), the Swedish University of Agricultural Sciences (SLU), RISE Research Institutes of Sweden and Processum.

Bio4Energy's research is at the international forefront and covers the entire value chain: From residual biomass feedstocks to end-products in the form of advanced biofuels, bio-based materials, and "green" chemicals. Our vision is to create environmentally friendly and sustainable technologies; alternatives to today's petrol-based systems.

Bio4Energy researchers collaborate with academia, research institutes and industry worldwide. The scientific researchers are active in education and competence supply at undergraduate, advanced and doctoral levels.

The research environment has been in operation since 2010 and involves over 200 researchers. More than 100 PhD students have graduated from Bio4Energy and our research has resulted in more than 2000 peer-reviewed scientific publications and over 50 patent applications.

Organisation and contact details

Bio4Energy is organised into seven research platforms, each with its own special focus in the biorefinery value chain, as illustrated in the figure on the frontpage and described further in the following pages.

The management team and the communications officer are listed below:

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Introduction – overview of 2023

The year of 2023 has been a challenging year in the world around us, with continued war and unrest, and at the same time continued alarming reports that we will not meet the global 1.5-degree climate target with current climate policy. At the same time, northern Sweden is buzzing with activity, as the interest in the region and in the industry's green transition continues increasing. Bio4Energy's research is largely motivated by the challenge of finding sustainable solutions for the climate, environment and society. We also now see an increasing significance of much of our research. Two notable areas are (1) energy security, where bioenergy is an important and inevitable complement to electricity – both in terms of bio-based heat and power production and for production of bio-electro-fuels and -chemicals, and (2) the development of domestically sourced materials and products, such as fertilisers, polymeric materials and "green" steel.

We are thus happy to be able to continue contributing to both education and research within this critical area.

The year in numbers

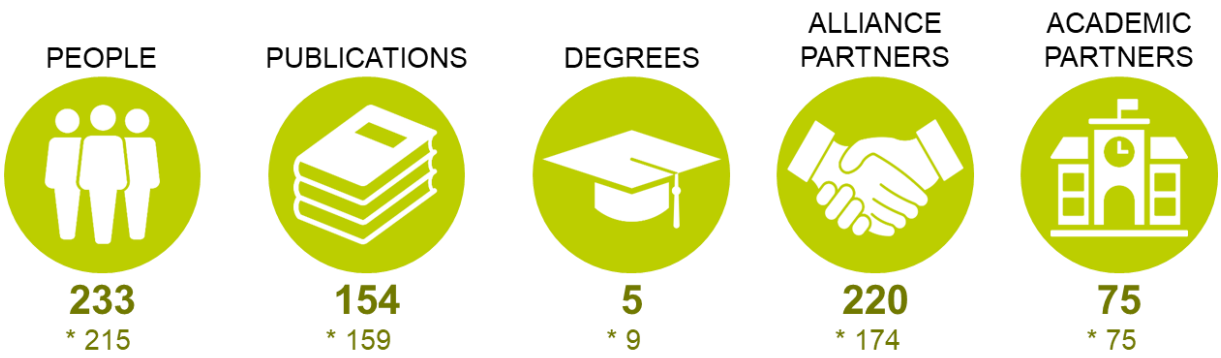
The figure below summarises a few of Bio4Energy's achievements of 2023 in numbers.

People are our most valuable assets! During the last decade, the number of researchers involved in Bio4Energy has been relatively stable at a bit over 200 persons. The last years show an upwards trend, with 2023 hitting the highest number of involved researchers since 2015.

PhD degrees are one of the ways in which we contribute directly to society and industry – through providing competence for the future. After an exceptionally high number in this area in 2022, we are now in more of a build-up phase again where many new PhD students have been recruited during the year.

Publications is how most our research is disseminated. Of the 154 published peer-reviewed journal papers in 2023, over 45 are a direct result of cross-platform collaboration, which means that researchers from two or more of the seven Bio4Energy research platforms have been involved. An all-time high!

Alliance partners and *academic partners* represent national and international collaborations, a central part of Bio4Energy's operations. After a few slower years during the pandemic, our number of collaborations started bouncing back up already in 2022 and hit an all-time high in 2023.



***Key numbers for Bio4Energy 2023**. Numbers marked with * are average values for the period 2016-2023. 'Degrees' here represents PhD degrees. 'Alliance partners' represents our external collaboration partners from industry, society and institutes, and 'Academic partners' our external collaborations with academic departments outside Bio4Energy.*

BIO4ENERGY

Research highlights from the platforms

The following pages are dedicated to highlights from the seven research platforms from the previous year, with brief descriptions of each platform's scope. Particular focus is here placed on new scientific results and achievements – or in short, we here give to you the quick flyover and a selection of insights from the over 150 scientific publications of 2023.

P1 Systems Analysis and Bioeconomy (SysAnaBio)

Biorefineries are inherently interconnected with existing industrial infrastructures and other sectors of the economy, and the related scientific-technological challenges are multifaceted and require a multi-disciplinary perspective.
In this platform, holistic and comprehensive methodological systems analysis approaches are used to address technological, economic, and social challenges and opportunities related to the development of biorefineries.

Platform leader: Robert Lundmark, LTU, robert.lundmark@ltu.se

- Showed that large-scale demonstration plants (PDP) are instrumental to pro-actively build business ecosystems around new technologies, such as bio-refineries. PDPs contribute to supply uncertainty reduction through three main enabling mechanisms: building credibility for the technology, business ecosystem orchestration, and technology learning. The corresponding enabling mechanisms behind demand uncertainty reduction include technology standardization, constructing the narrative, and the creation of legitimacy for the technology. The results indicate that it is essential to verify the entire value chain and for policymakers to ensure that the whole value chain is included in the incentive programs.
- Examined seven SAF production path-ways with bio-energy carbon capture (BECCS) or utilisation (BECCU), motivated by that mitigation of the climate impact of aviation remains challenging due to limited electrification options and high-altitude combustion. We showed that BECCS can achieve negative carbon footprints and lower GHG reduction costs, while BECCU displayed higher costs and GHG footprints, due to electricity-intensive carbon dioxide upgrading. Pathways based on biomass gasification, or fermentation of forest residues, showed low GHG reduction costs coupled with large feedstock potential. These findings can assist policymakers and industry in selecting cost and carbon efficient SAF production strategies.
- The policy mixes and policy feedback in the emergence of domestic green industries, such as biofuel production, influence the co-evolution of technology, and industry structure and growth. We showed that policy feedback dynamics have created difficulties in aligning the national policy mix with the technology and industrial developments in the country. The resulting political un-certainty predominantly has hampered the scaling up of domestic production capacity, while R&D and import of biofuels instead could grow strong. Based on a process model explaining the role of policy feedback in the development of domestic industries, we showed that future research into the role of policies in "green" domestic industry growth should devote more attention to the dynamics driving the co-evolution of policy, technology, and industry structures.

- Finalised large interdisciplinary project targeting utilisation of infrastructure for organic waste treatment in Sweden, in particular sewage sludge, for increased production of high-value materials and energy carriers, reduced use of primary resources, and improved economic performance (collaboration with P4, ThermoChem). We found that a mish-mash of different barriers – technical, economic, legal, and related to public perception – creates uncertainty that hinders progress regarding both sustainable long-term strategies and technological advancement. The Swedish sewage sludge management is largely fragmented, and there is a need to shift direction to a more holistic approach, to help actors address common issues rather than focussing solely on activity-specific problems. Introducing new legislation could be a key step, as the current specific legislation on sewage sludge has a seemingly insignificant role for today's sludge management, compared to other legislation and the voluntary certification (REVAQ).
- Presented a report on the role of forests in the energy and climate transition at SNS (Center for Business and Policy Studies). The presentation was broadcasted on SVT Forum on several occasions. The report applies a wide perspective on both social and private benefits (and costs) of different ecosystem services, including timber production, recreation, carbon sink and biodiversity. The purpose is to illustrate trade-offs and synergies between different potential pathways. The findings will assist both industrial and political decision-makers to navigate between the economic value of different ecosystem service and help formulate informed decision on necessary trade-off.

P2 Forest-Based Feedstocks (ForFeed)

Feedstock is the basis of all other platforms, and optimised feedstock will influence the whole value chain. Research on feedstock production systems contributes to increased wood yield and allows engineering of wood characteristics. Within this platform, genetic and molecular control of properties that are important for feedstock biorefining are investigated, as well as how these properties are governed by environment and management practices.

Platform leader: Hannele Tuominen, SLU, hannele.tuominen@slu.se

- Established an optimal thinning procedure in hybrid poplar (*Populus maximowiczii* × *P. trichocarpa*) clone OP42 plantations. Four different thinning treatments were tested in a plantation in Southern Sweden seven years after the first rotation harvest. Eleven years after thinning, a procedure comprising 1100 stems per ha was demonstrated as one resulting in highest biomass production.
- A genetic study in 1654 Norway spruce trees suggested that tree growth rhythms adapt to the latitudinal variation according to the prevailing light conditions, in particular the ambient light red/far red ratio. This knowledge could be applied to designing strategies in breeding programs for Norway spruce.
- Long-term poplar plantations were predicted in a theoretical study, combined with fuel analyses of 12- and 30-year-old poplar stands, to produce annually 10 million Mg dry weight (DW) or 48 TWh. The study concluded that using 25% of the available land, 7.7 TWh methanol biofuels could annually be produced from 16 biofuel production plants, using 160,000 Mg DW per year. Furthermore, biomasses from long-rotation poplar plantations were shown to have fuel characteristics similar to conifer tree species.

- Developed surveillance routines to monitor disease outbreaks of pine twisting rust (*Melampsora pinitorqua*) which is of concern in Swedish forests. Correlative analyses demonstrated in aspen leaves that visible rust scores or condensed tannin concentration cannot be used to assess *Melampsora* infestation. However, PCR with species-specific primers could detect the native *Melampsora* rust.
- Characterised natural variation in tree growth, wood properties and biorefining potential in 112 Swedish aspen trees. In addition to a few genetic markers, simple volumetric growth traits were identified as good predictors for the overall biorefining potential of the aspen feedstocks.
- Discovered that wood cell walls contain lipids which are not extractable and that xylan side chain - glucuronic acid is responsible for fastening these lipids to cell wall matrix.
- Developed novel methods for automatic counting of resin ducts in SilviScan microscopy images, NIR imaging of tangential wood surfaces, analysis of 5 mm diameter increment cores with SilviScan and NIR-camera, protoplast cell wall regeneration, and image segmentation for identification of individual fiber and vessels in wood macerates. Also, we established a new isotope labelling system for the analysis of carbon fluxes in trees.
- Identified in five-year field trials that suppression of a novel type of a dehydrogenase enzymes in transgenic aspen trees improved conversion of wood to sugars after acid pretreatment of wood. The pretreatment process was applied at the laboratory and at semi-industrial scale at Processum, with similar results.
- Identified a novel player in xylan biosynthesis – atypical aspartic protease 1 – based on downregulation of transcript levels in developing wood. The suppressed lines were tested in field trials for 5 years after which the wood was observed to contain less xylan. This resulted in better saccharification yields without pretreatment. Similar result was observed in all tested xylan-reduced lines including GATL1.1-suppressed lines and GT43BC-suppressed lines, previously patented based on greenhouse tests.

P3 Feedstock Pre-Processing (FeedPro)

Forest-based lignocelluloses are characterised by their structural and chemical diversity. Expertise in advanced feedstock characterisation and design and evaluation of tailored pre-processing technologies is critical for accelerating the development of biorefinery processes and products. This platform addresses challenges and opportunities caused by biomass heterogeneity, through research on characterisation, separation, and modification of bio-based materials.

Platform leader: Mikael Thyrel, SLU, mikael.thyrel@slu.se

- Used multi-criteria decision analysis (MCDA) to rank 88 types of pellets for energy use produced from under-utilised forest and agricultural biomass, in order to facilitate decision-making. In total, 18 scenarios were modelled with varying risks and criteria weight inputs. In all scenarios, pellets produced from spruce/ pine sawdust blend were ranked highest, with Scot's pine bark being second-best overall. Noticeably, torrefied pellets were ranked last in all scenarios which mainly was attributed to the fact that the high cost of torrefaction did not justify the benefits of an improved pellet quality.
- Characterised the ash from co-combustion of bark and two types of sludges for its potential as a resource-

efficient and sustainable phosphorus fertiliser. Detailed chemical and synchrotron-based X-ray tomography revealed the potential for using slag particles as soil enhancers or for recovery processes, especially from the combustion of 30% biosludge and 70% bark. This research underscores the potential for sustainable resource utilisation, offering a hopeful outlook for the future.

- Showed that the utilisation of Norway spruce bark to produce activated carbon with zinc chloride as an activator has significant implications for the fields of materials science, environmental science, and energy storage. Optimal preparation conditions, determined via response surface methodology, enabled production of activated carbons with predominantly mesoporous structures, high carbon content, low ash content, and favourable chemical composition. These properties make them effective adsorbents for removing sodium diclofenac from water, a crucial step in environmental remediation.
- Demonstrated a novel approach to use spent mushroom substrates (SMS) from shiitake cultivation as a carbon precursor for producing nitrogen-doped (melanin) activated biochar via pyrolysis. The melanin-doping provides added N-functionalities to the porous carbons, significantly improving the efficiency in removing contaminants in synthetic effluents and sewage water. This innovative use of SMS showcases its potential as a valuable waste for producing activated carbons, sparking new avenues for waste management and resource utilisation.

P4 Thermochemical Conversion Technologies (ThermoChem)

Through thermochemical conversion processes, widely different types of biomass can be converted into advanced fuels and chemicals. The overall challenge for this platform involves generating the fundamental understanding needed to support the technical development of thermochemical conversion of forest-based biomass, side streams, recycled fibres, underutilised fractions, and to make the corresponding technologies competitive to those for fossil fuels.

Platform leader: Markus Broström, UMU, markus.brostrom@umu.se

- Published new information on the potential for altering phoshporus (P) species toward potassium- (K-) bearing phosphates during the combustion and gasification of P-rich sewage sludge and mixtures with K-rich agricultural residues
- Demonstrated the feasibility of using feldspar as an alternative bed material in fluidised bed processes to substitute commonly used bed materials with problematic properties in terms of heavy metal content (olivine) and process stability, e.g., bed agglomeration tendency and fragmentation (quartz).
- Development of PF-TDLAS (photofragmentation spectroscopy with tunable diode laser absorption spectroscopy), a novel method for quantitative, in situ, simultaneous detection of atomic potassium (K), potassium hydroxide (KOH) and potassium chloride (KCl). The method is based on absorption spectroscopy of K atoms and K fragments produced by photofragmentation of KOH and KCl. In addition, the technique can be used to study the K reaction kinetics by monitoring of the post-fragmentation decay of the K fragments.
- Performed quasi-continuous measurements of K species concentrations in a pilot-scale (140 kW) entrained-flow biomass gasifier using PF-TDLAS for two different fuels. Measurements were in reasonable agreement with equilibrium calculations.

- Studied and demonstrated biofuels as an option for fossil fuels in limekilns in a joint project between Nordkalk AB and the Centre for Sustainable Cement and Quicklime Production at Umeå University, called Renewable energy carriers in quicklime production. Drastic emission reductions have been achieved already during the time span of the project.

P5 Biopolymers & Biochemical Conversion Technologies (BioPolChem)

This platform focuses on bio-based polymers for advanced and sustainable materials, and conversion processes that involve microorganisms and enzymes. Both conventional forest-industrial processes and products, e.g. cellulose and cellulose derivatives, and novel polymeric bio-based materials are included. Exploitation of the inherent characteristics of the raw materials is central, incorporating the sustainability aspect to reduce, recycle, and reuse.

Platform leader: Leif Jönsson, UMU, leif.jonsson@umu.se

- Developed a bioprocess engineering approach for producing hydrocarbons from green microalgae in a multi-cultivator airlift photobioreactor. The process was also optimised for scale-up process in the raceway open pond system. Furthermore, pyrolysis experiments on microalgal green biomass and de-oiled biomass revealed lipid and hydrocarbon compounds generated by the thermal degradation of *B. braunii,* that facilitate extra economical value to this system.
- Studied the application of ternary solvent systems for the fractionation of hardwood biomass, resulting in a pulp with as high as 94% cellulose and as low as 5% lignin (up to 95% delignification) and complete removal of hemicellulose. The research resulted in ultra-high purity of lignin, reaching sugar impurities of less than 0.8%. Novel insights were obtained by applying a combination of lignin analytics and we also demonstrated the presence of two type of furans in the lignin isolate, which is dependent on the organosolv process parameters. We also showed that sulfuric acid eventually converts side-chains into short oxidised functionalities.
- Showed metabolic insights into diversion of hydrophobic waste towards omega (ω) fatty acid in microalgae, through development of omics tools to uncover alternative pathways for ω-3 fatty acid synthesis and genome-wide regulation in response to cultivation parameters of microalgae. We also emphasised potential targets to fine-tune in order to enhance yield. Despite progress, an integrated omics platform is essential to overcome current bottlenecks in optimizing the process for ω-3 fatty acid production from microalgae, to advance this crucial field.
- Worked with collaborators for the preparation and testing of lignin-based antifouling coatings, for lignin valorisation. Moreover, we demonstrated that lignin enhances the corrosion and wear resistance of polyurethane-based coatings.
- Established a lignin fractionation method for the selection of specific lignin subunits that are tailored for different applications. We also demonstrated that native lignins require chain untangling in order to display their full antioxidant activity.
- Expanded the portfolio of lignocellulosic feedstocks, through initiating research on the fractionation of forest harvesting residues (GROT) biomass with the first trials showing promising results.

- Investigated the potential of using mine tailings to boost the chemo-enzymatic capturing of carbon dioxide by using carbonic anhydrase. Performed in collaboration with Boliden, LKAB and Copperstone under the prestigious Industriklivet project TAILOR-MADE, funded by the Swedish Energy Agency.
- Developed an energy-efficient fibrillation method of biologically pretreated wood, which has shown new functional properties.
- Developed a composite manufacturing process for used textiles. Recycling of textiles is rare in Sweden and in Europe, and used textiles, such as clothes, sometimes go to landfill thus wasting huge amounts of unused raw material in the form of cellulose fibres that could be used as reinforcement material in composites. A manufacturing process for the recycling of textiles in composites was developed, which is environmentally friendly and simple and does not use water, chemicals or energy-intensive mechanical processes. A compounding extruder was used for this, a typical process equipment also used in the plastics industry to make the composite material. Textiles are cut into strips (similar to carpet rags) and fed into the extruder together with the plastic, and are broken down into fibres and mixed with the polymer. The composite with 40% recycled textile fibres has potential to be cheaper and stronger than the single polymer and to contribute to circular economy and reduced clothing waste.
- Developed a natural biodegradable hydrogel from brown kelp, *Laminaria Hyperboream,* that allows for resource- and energy-efficient engineering of e.g. wound dressing or 3D-printed artificial body tissue. The patent was bought by Norwegian company Alginor ASA, who are currently building a processing plant for north Atlantic seaweed.
- Initiated the first research projects in which the new RISE High-Throughput Center is being used, in collaboration with Processum and with the support of Kempe Foundations.

P6 Chemical Catalysis and Separation Technologies (CatSep)

In order to make biorefineries successful, it is essential to develop suitable catalysts and energy lean separation technologies. The focus of this platform is fundamental research on novel integrated catalysis and separation processes designed for application in forest and other lignocellulosic-based biorefineries, encompassing both thermochemical and biochemical routes to fuels and chemicals.

Platform leader: Jonas Hedlund, LTU, jonas.hedlund@ltu.se

- Developed exceptionally selective and permeable DDR zeolite membranes.
- Made good progress on the synthesis of jet fuel components from methanol.
- Invited to give the first lecture (Plenary lecture 1) at the International Zeolite Membrane Meeting in Nanjing, China.
- Several start-up companies operate out of this platform, notably ZeoMem Sweden AB who sold their first zeolite membranes for commercial gas separation in 2023, as well as Spinchem AB and ECO-OIL AB.

P7 Environment and Nutrient Recycling (EnviroNut)

One of the key challenges when introducing new biorefinery concepts is to develop sustainable and resource-efficient utilisation routes of forestry biomass, industrial residues and organic waste streams, including closing the loops of nutrients and minerals, as well as minimising the potential environmental and health impacts. This platform aims at advancing the understanding related to critical research questions on the environmental aspects of sustainable forestry, bioenergy and biorefinery processes.

Platform leader: Nils Skoglund, UMU, nils.skoglund@chem.umu.se

- Performed further evaluation of ash potential in pit lakes and how algal growth is affected. Additional funding was secured to carry out additional mesocosm studies as well as a full-scale study.
- Significantly contributed to the debate around forest management systems by scrutinizing the evidence for the so-called Mother tree hypothesis.
- Showed that nitrogen fertilisation leads to a dramatic change in tree biomass allocation. This means that claims for using nitrogen fertilisation for carbon sequestration will overestimate the actual rate of sequestration.
- Investigated (proof of concept) for circular and sustainable production of bioplastics from aquatic biomass with the help of photosynthetic microorganisms, (collaboration with P5, BioPolChem and P1, SysAnaBio). The research places focus on how carbon atoms can provide functionality more than once.
- The research performed at Synchrotron Soleil and beamline Anatomix, France (collaboration between Bio4Energy platforms P7 and P3) received special attention from this large-scale research infrastructure. The published paper on morphology of phosphorus-rich ash particles from waste streams in pulp and paper industry was selected for Soleil's 2023 Highlights where especially novel research topics are summarized.

New strategic projects

Twenty percent of all funding to Bio4Energy is set aside as **Strategic Funds** used to create synergies and explore and address new and important avenues of research.

Our strategic projects:

- Concern high-quality research dedicated to the biorefinery field;
- Involve collaboration between research and development platforms and research groups;
- Are targeted at finding solutions to global problems and strengthening the development and competitiveness of Sweden and Swedish industry and;
- Support young Bio4Energy researchers in a critical phase of their academic career.

In the 2023 call for **targeted strategic funds (2024-2025)**, nine 2-year projects were granted, according to below.

Forest residues for developing next-generation sustainable lithium-ion batteries

Glaydson Simoes dos Reis (SLU, P3), Jyri-Pekka Mikkola (UMU, P6), Xiaoyan Ji (LTU, P6)

Bio2Char - Pre-feasibility study of new residual streams as feedstock for production of biochar for industrial applications

Elisabeth Wetterlund (LTU, P1), Dan Bergström (SLU, P1), Åsa Lindman (LTU, P1), Kentaro Umeki (LTU, P4)

Sustainable packaging materials from renewable raw materials sources

Kristiina Oksman (LTU, P5), Sandra Winestrand (UMU, P5)

Doped biochar materials for biobased batteries – in-situ characterisation and understanding of structural versus electrochemical properties (BioBat)

Anna Strandberg (UMU, P3), Shaojun Xiong (SLU, P3)

Enabling low-grade biomass and waste combustion with reduced CO_2 emissions - in situ measurements and impact on policy design

Florian Schmidt (UMU, P4), Robert Lundmark (LTU, P1), Henrik Wiinikka (LTU, P4), Alexey Sepman (RISE, P4)

Development of a novel tool for evaluation of the mechanical properties of wood

Ewa Mellerowicz (SLU, P2), Laura Bacete (UmU, P2), Dusan Petrovic (RISE, P2)

Multiscale mechanical, chemical and structural properties of aspen wood

Stéphane Verger (UMU, P2), Hannele Tuominen (SLU, P2), Peter Nordström (RISE, P2)

Nitrogen in biochars from biomass residual streams – forms, fate and plant availability in soils

Christoffer Boman (UMU, P7), Sandra Jämtgård (SLU, P7)

Revitalizing forest waste into microalgal & bacterial cellulose membranes with tailored properties for sustainable food packaging (Green Tech)

Alok Kumar Patel (LTU, P5), Kerstin Ramser (LTU, P4)

Bio4Energy graduate school

The **Bio4Energy Graduate School** currently comprises three courses for PhD students and early career scientists. In 2023, the graduate school's newest course "Historical, technological and societal background to forestry and forest-based biorefining in Nordic countries" was given for the first time.

During 2023, Bio4Energy had 79 active PhD students. Five doctoral theses and one licentiate thesis were defended in 2023. Big congratulations to you all!

PhD theses

Atanu Kumar Das, SLU, Forest biomaterials and technology (P3)
Production and characterisation of pine wood powders from a multi-blade shaft mill
Main supervisor: Magnus Rudolfsson

Thomas Hannl, LTU, Dept. of Engineering Sciences and Mathematics (P4)
Fluidized bed combustion and gasification for phosphorus recovery by co-conversion of sewage sludge with biomass
Main supervisor: Marcus Öhman

Emil Thorin, UMU, TFE (P4)
Quantitative laser diagnostics of gas-phase potassium species in biomass combustion and gasification
Main supervisor: Florian Schmidt

Naresh Kumar Wagri, UMU, TFE (P4)
Assessment of bio-based fuel ash effects on magnesia refractory materials in quicklime production kilns
Main supervisor: Britt Andersson

Pierre Oesterle, UMU, Dept. of Chemistry (P7)
Exploring the fate of emerging contaminants during hydrothermal regeneration of carbonaceous adsorbents
Main supervisor: Stina Jansson

Licentiate thesis

Jiajia Li, LTU, Dept. of Engineering Sciences and Mathematics (P6)
Constructing poly(ionic liquid)s-based composite solid state electrolytes and application in lithium metal batteries
Main supervisor: Xiaoyan Ji

Communication and outreach activities

Bio4Energy's external communication activities include both a website and newsletters, as well as activity on social media. Our communication centers around a combination of strong research news, highlights of Bio4Energy people who are praised for their efforts, and our place in the sector as a partner. In 2023, news about education have had a central place, since we launched a new course in the Bio4Energy graduate school, as mentioned above.

Topics that received notable attention in news and media during the year include:

- Fast-growing broadleaf trees with good profitability.
- Second generation poplar grow faster than the first generation.
- Biobased batteries.
- Upgrading mining residues to capture carbon dioxide.
- Biodegradable hydrogels from algae.

Bio4Energy also communicates research findings through other outreach activities. A few examples from 2023 are:

- Christoffer Boman and Stina Jansson (EnviroNut, UMU) contributed on several occasions under the theme "Samhälls-omvandling i Norr". Their expertise from energy, environment, and challenges with pollutants in waste streams are important contributions to the societal debate and understanding of how waste streams can be valorised and safely managed.
- Linn Berglund (BioPolChem) participated in UR Vetenskap on the topic "Sweden researches: The super patch that heals all wounds".
- Popular scientific lectures and presentations in various contexts, of which a few examples during 2023 were during science lunch at Curiosum in Umeå on the topic of how we get rid of "eternal chemicals", at Kunskapsnoden in Stockholm on the topic of that the future's energy may reside in different waste products, and at an IEA Bioenergy workshop in Canada on the topic of synergies of green hydrogen and bio-based value chains deployment.
- Partnered with Svebio, Bioenergi magazine and Bioenergy International in organizing the annual Advanced Biofuel Conference, ABC, in Gothenburg.

New equipment and research infrastructure

Bio4Energy funding has over the years been instrumental in enabling the procurement of research infrastructure and equipment. Notable examples for 2023 are:

- Multi-purpose Adaptive X-ray Scattering platform (MAXS), which was procured with support from Kempe foundations, Umeå University Vice-chancellor, Umeå University Faculty of Science and Technology, with Bio4Energy making an important contribution towards the final configuration. The analytical platform enables advanced X-ray scattering analysis offering powder diffraction, X-ray reflectometry, total X-ray scattering, and a large range of sample stages. The MAXS platform is hosted by EnviroNut platform leader Nils Skoglund and will be fully operational and available to Bio4Energy researchers in spring 2024.
- The Frontier PY-3030S Single-Shot Pyrolyzer is a pyrolyzer specifically designed for flash pyrolysis. The system is ideal for basic polymer research as well as quality control of polymeric products. It is simple but effective for any type of isothermal sample introduction to GC or GC/MS from 40-800°C. The Frontier single-shot pyrolyzer has precise temperature control, uses the same low dead volume, inert, and heated flow path as the EGA/PY-3030D multi-shot pyrolyzer, and can use a variety of analytical techniques. The equipment is

hosted by BioPolChem researcher Alok Patel.

- A 50-L stirred batch reactor has been commissioned for the scale-up of organosolv fractionation within the BioPolChem platform. The reactor has been successfully tested with halophyte and forest biomass and demonstrated fast heating and cooling rates.
- An Ion-Chromatography System Dionex ICS-6000, HPAEC analyses has been procured to UMU Department of Chemistry for use for collaborations both within the BioPolChem platform, and with the ForFeed, FeedPro and EnviroNut platforms.

Bio4Energy Advisory Board

During 2023, we have had two meetings with Bio4Energy's external Advisory Board:

- A digital meeting in January, on the theme "Outlook for the future"
- A physical meeting at Stockholm Exergi, on the theme "(Bio-)CCS/CCU"

In addition to presentations from several Bio4Energy researchers from different platforms and from our Advisory Board members, the meetings also have included addresses from invited external presenters.

Peter Axegård
C-Green Technology AB
Senior Advisor

Charlotte Bengtsson
Skogforsk
CEO

Erik Dotzauer
Stockholm Exergi
Policy expert

Ann-Britt Edfast
Edfast & Wallén konsult

Björn Fredriksson-Möller
Öresundskraft
(formerly at St1 Biogas)

Anna Karlberg
Stora Enso
VP Forest R&D

Johanna Mossberg
RISE
VP Biorefinery & Energy

Torgny Persson
Swedish Forest Industries
R&I director

Linda Werner
St1
Head of Future
Upstream

Martin Wimby
Valmet Recovery
Business Unit
Technology Director