



Annual report 2019



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Introduction – overview of 2019

The year of 2019 has been ordinary and unusual at the same time for Bio4Energy. As we are approaching the end of the second program period, work has increasingly started to be more forward-looking, with the re-launch of the Strategy Group and other preparations for a third program period. During the year, the research within the seven research platforms has in general proceeded as planned, and the research achievements have received scientific as well as societal attention.

This document aims to summarise the main activities within Bio4Energy during 2019. Each platform has been asked to highlight a selection of interesting or important research-related activities and achievements from the year. This has been complemented with summaries on media and outreach, PhD education, and other noteworthy accomplishments.

Research activities at the respective platforms

This section summarises a selection of research activities and achievements within the respective platforms during 2019.

P1 Systems analysis and bioeconomy

Platform highlights:

- Data envelopment analysis (DEA) has been used to analyse attainable, and sustainable, efficiency improvements in the harvesting of forest products. The results show that the harvested volumes of forest products, both for the industry and energy sectors, can be significantly increased if a more efficient forest management is adopted.
- An interdisciplinary model framework has been developed that enables the inclusion of market aspects (through micro-economic partial equilibrium modelling) in techno-economic and supply chain modelling of biorefinery value chains. The approach has been applied on the case of LBG production integrated with sawmills.
- Environmental impact and environmental cost of methanol production from woody biomass by novel and conventional methods has been assessed.
- Analysis of environmental performance and sustainable return on investment under different propulsion modes, for different light-weight car materials.
- Analysis of the roles of pilot and demonstration plants in bringing novel sustainable technologies to the market, in the empirical context of the development of biorefinery technology. Areas of investigation includes an innovation system perspective, network and actor roles, managerial and organisational challenges and solutions, and the need for an innovation policy mix.

New research initiatives have started based on collaborative efforts and external funding. This includes: (a) Methodological development regarding interdisciplinary linking of system models and methods; (b) assessment of carbon accounting and efficiency when e.g., comparing biorefinery products and concepts; (c) an integrated assessment of forest and forest products utilisation in terms of climate impact; and (d) evaluation of different bioethanol production systems. External grants include approved applications to, e.g., VR, Formas and the Swedish Energy Agency.

Platform researchers have during 2019 also established new context-specific collaborations with academic, societal and industrial partners. This includes collaboration in a project to produce jet fuel from forest residues in Småland (e.g., Södra, KLM and Växjö Airport), and collaboration with the Swedish Homeowners Association on heating and energy efficiency.

Several new internal Bio4Energy collaborative constellations have also been introduced during 2019, e.g., with the thermochemical platform on suitable residual feedstocks for biochar production for use as reducing agent in the Höganäs sponge iron process, and on the potential to obtain useful products from co-combustion of different biomass residues and digestate from sewage sludge treatment.

P2 Feedstock

Platform highlights:

- A new annotation of poplar carbohydrate active enzymes. The annotation is a major update since the first poplar genome was released in 2006, and facilitates studies on cell wall biosynthesis and wood formation.
- Reduced biomass acetylation improves saccharification properties in aspen. New acetylation-reduced hybrid aspen lines were selected for field trials based on increased saccharification potential and good greenhouse performance.
- Identification of the plant hormone ethylene linked molecular factors (ERFs) that control xylem differentiation in aspen trees. For example ERF85 regulates the onset of secondary cell wall formation and hence the bulk biomass accumulation in aspen trees while ERF139 regulates lignification. Modification of these kind of factors help us develop methods to improve feedstock properties in trees.
- Genome-Wide Association Study (GWAS) identified novel candidate loci affecting wood formation in Norway spruce. The results advanced our understanding of the genetics influencing wood traits and identified candidate genes for future functional studies.
- Near Infrared (NIR)-spectral data acquisition was optimized for both spruce and aspen wood chemistry determination. The method facilitates the identification of the links between wood chemistry and genetics.
- A new software was developed called SurfCut, which allows user friendly and automated characterization of plant cell shapes.
- A simplified model of the cell wall mechanics was developed to provide insights into how plants perceive mechanical stress.

Bio4Energy has facilitated a number of new collaborative projects related to the platform. For example, a collaboration with RISE researchers was initiated to investigate 1) the transition from earlywood to latewood formation and the underlying molecular mechanisms, and 2) how to predict cell wall chemistry and wall thickness from NIR data in aspen. New collaborations were also planned or started with KTH as well as Skogforsk and University of Freiburg.

Bio4Energy funding also allowed for acquiring new equipment, as well as a new collaboration to investigate the use of the Synchrotron Soleil in Paris for the identification of symbiotic fungi.

P3 Wood pre-processing

Platform highlights:

- A concept of biological pretreatment of lignocellulosic biomass by combined cultivation of edible mushrooms and lignin degradation for ethanol production was successfully introduced. Mushroom cultivation reduces the mass fraction of lignin in the substrate to less than half of the initial.
- Hot-air pasteurization was introduced as an alternative method to autoclaving for disinfection of mushroom cultivation wood chip substrate. This novel method reduces cost and improves mushroom growth and yield.

- The ethanol production potential of cassava stems, which have a global annual production of 30 Mton DM, can through a two-step hydrolysis method be improved to approach the theoretical maximum of 300 L/ton TS.
- Al-rich chemical sludge from the pulp and paper industry can be used as an additive to reduce slagging tendencies of other solid biomass fuels.
- By combining NIR and XRF spectroscopy, inherent ash and ash from inorganic contamination can be separated.
- The soil amendment performance of biochars from different biomasses is highly dependent on the choice of thermal treatment method. HTC chars have good properties for improving the soil aggregate stability but do not improve (or are even reducing) the soil's water-holding capacity. Slow pyrolysis chars have the opposite properties.
- Through synchrotron-based 3D X-ray micro-tomography, the thermal conversion of biofuel pellets was studied in detail and it was revealed that large cracks and internal cavities developed already during devolatilization. Wood pellets had a 64% void fraction after the devolatilization stage without the outer layer pellet structure collapsing.
- Water sorption properties are important for charge storage ability in electrodes prepared from activated and non-activated reduced graphene (a-rGO and rGO). A more hydrophilic surface is favourable for the performance supercapacitors with KOH electrolyte.

The platform has an established a position in Treesearch with two PIs, one as coordinator for SLU's participation and one as representative in the scientific committee. Also, a one-year postdoc position and an industrial PhD student is partly funded by Treesearch.

Bio4Energy has also enabled the employment of two postdocs, two PhD students and two researchers, the procurement of an on-line neutron analysis instrument (co-funding by Kempestiftelserna), new projects within the BioInnovation and Resource programs, and the set-up of a combined gasification and biochar reactor at the Biomass Technology Centre, SLU, Umeå.

P4 Thermochemical conversion technologies

Platform highlights:

- Cross-platform research has resulted in a number of publications, related to, e.g., i) the effects of pyrolysis conditions and feedstocks on the properties and gasification reactivity of charcoal from woodchips, ii) ash and slag formation, transformation and properties in combustion processes, and iii) alloy degradation in CFB biomass co-firing.
- Institute research collaborations have also resulted in a number of publications related to, e.g., i) spray combustion of biomass fast pyrolysis oil, ii) effects of co-firing coal and woody biomass upon the slagging/deposition tendency in iron-ore pelletizing grate-kiln plants, and iii) development of non-intrusive diagnostics methods in biomass combustion and gasification processes.
- Development of a versatile sensor for simultaneous in situ detection of K(g), KOH and KCl in biomass combustion and gasification environments. The sensor is based on UV photofragmentation combined with tunable diode laser absorption spectroscopy.
- The novel concepts for cyclone gasification- and pyrolysis of biomass was further developed at RISE ETC in national and international collaborations, e.g. within the EU project "Biomates" (<http://www.biomates.eu/>)
- The participation of the B4E thermochemical platform in the Bio4Gasification (B4G) node of Swedish Gasification Centre (SFC) received very positive feedback in an external evaluation of SFC, concluding that novel, world-leading research is being performed within the area of biomass gasification.

During the year, new and strengthened collaborations between Bio4Energy research within the thermochemical platform and different industrial sectors have been established to promote the transformation to fossil-free and sustainable production systems; both with the steel, and with the cement- and quicklime industries. Researchers from the thermochemical platform also became new participants in the above mentioned Treesearch platform.

Bio4Energy has also enabled the recruitment of a new guest professor (Flemming Frandsen, from DTU, 30% position at UmU), who is one of the world leading researchers in this area and he will therefore increase the scientific excellence of Bio4Energy. The procurement of new infrastructure was also enabled by support from Bio4Energy; i) Powder XRD (RISE ETC), ii) TGA-DTA/DSC (RISE ETC), iii) Fixed bed down-draft gasifier reactor for continuous generation of electricity and designed biochar (UmU, SLU).

P5 Biopolymers and biochemical conversion technologies

Platform highlights:

- Research on Organosolv Lignin Nanoparticles (OLN) for flotation of Cu, Zn, Pb and Ni for the mining industry resulted in one patent, three publications, two Vinnova projects (Boliden, Nouryon, Sveaskog), and the 4-year project BATTERFLAI funded by EIT RawMaterials.
- Nutraceuticals from lignocellulosic biomass, docosahexaenoic acid (DHA, an omega-3 fatty acid) and squalene, were produced using marine oleaginous microorganisms (Thraustochytrids).
- New project on bark valorization received support from the Swedish Energy Agency: Bark Conversion into Green Fuels (BarkGF).
- Light-weight nanocomposites were developed and studied in MAX IV and using WAXD and microtomography.
- Electrospun lignin nanofibers were developed.
- First publication on evaluation of a novel more resource-efficient type of wood chipping for forest-industrial applications. The research is based on collaboration with industrial partners in Örnsköldsvik.

Also researchers from the BioPolChem platform participate in Treesearch, with special focus on wood and bionanocomposites, and pretreatment and fractionation of the wood raw material.

P6 Chemical catalysis and separation technologies

Platform highlights:

- By combination of experiments and mathematical modelling, researchers from the platform for the first time showed that the mass transport of small molecules in zeolite crystals is desorption-limited. A first manuscript describing the results has been submitted. This observation is of high scientific and practical importance. The scientific importance rest on that the desorption step is one of the three fundamental steps that must occur in any mass transfer process. The practical importance is a consequence of that small zeolite crystals are used in numerous current industrial processes and many of these processes may in fact be affected by desorption limitations.
- The developed mathematical model has been used to show that it is possible to design very efficient processes for e.g. biogas-upgrading by CO₂ separation. The new processes have much reduced electricity consumption, footprint and costs compared to all current commercially available techniques.

- New process for the production of cellulose derivatives taking advantage on CO₂ and ionic liquids has been successfully demonstrated (and published). Also, the similar approach was used to produce acrylic plastic precursors as well as ethylene and propylene carbonate.
- New Deep Eutectic Solvent systems were introduced for the capture of carbon dioxide. Also, a thermodynamic model was developed that accurately explains the behaviour of the obtained solutions.
- Electro-chemical water splitting project has advanced and new, efficient, robust and cheap electrode materials were developed.

Major companies have shown significant interest in the membranes for CO₂ separation and are now testing or planning to test those. Letters of intent have also been signed with a few companies to advance the commercialization of the processes for production of renewable gasoline and diesel (ECO-OIL). Patents on both membrane preparation and diesel production have been granted or are pending.

P7 Environment and nutrient recycling

Platform highlights:

- A new extraction method was developed and tested for evaluation of regeneration properties of carbonaceous adsorbents, and has so far resulted in one publication.
- Characterization of so-called BMC materials ('biochar mineral composites') of spruce and bio-ash, a new product with unexplored potential for the recirculation of nutrients in forestry and agriculture. The results have been described in two publications.
- Collaboration with the systems analysis and bioeconomy platform on methods for environmental assessment of bioenergy scenarios. This has, for example, been exemplified in a publication on air pollution in developing countries.
- Full-scale demonstration of the "fuel design" concept to reduce the emission of fine particles into ambient air when combusting forest biofuels. Collaboration with the thermochemical platform, which has also resulted in a publication.
- Preliminary results from the Advanced Light Source synchrotron, USA, show that it is possible to measure the chemical environment around phosphorus in ash with X-ray spectroscopy, which is crucial for the direct recirculation of ashes from various sources to biomass production.

Bio4Energy has also enabled co-financing of one PhD student, and the initiation of several new collaboration projects. The project "SafeSed - Safe and non-destructive removal of contaminants from sediments" aims at in-situ detoxification of contaminated marine sediments outside, for example, sawmills and paper mills (partners are UmU, SGU, Sweco, Mora municipality, the spin-off company ENRES, and the US patent owner ecoSPEARS). The project "Strengthening capacity for sustainable bioenergy, waste management and air pollution control in Rwanda" is funded within the SIDA-UR Research and capacity building program, with partners from UmU, SLU, KTH and the University of Rwanda. Researchers in the platform have been also acting as guest researchers on issues related to the recovery of phosphorus from ash at Advanced Light Source, USA, TU-Wien, and Bioenergy and sustainable technologies (BEST), Austria.

New strategic projects

In the 2019 call for **free strategic funds**, eight projects were granted:

- Valorization of pulp and paper mill ashes and sludge by a two-step treatment approach – A feasibility study, Christoffer Boman, UmU, 635 kSEK (1 year)
- Modelling algal growth rate for biofertilizer and/or biofuels production, Francesco Gentili, 635 kSEK (1 year)
- Aromatics from lignin, Jonas Hedlund, LTU, 1135 kSEK (2 years)
- Samspel mellan gödning och tillväxt, torkriser och egenskaper i klimatperspektiv, Torgny Näsholm, SLU, 1135 kSEK (2 years)
- Carbonization of biomass to high quality renewable carbon materials for CO₂ capturing and energy storage, Kristiina Oksman, LTU, 1135 kSEK (2 years)
- Resolving the determinants of lignocellulose recalcitrance to bioconversion in situ at a micrometre scale with imaging techniques, Hannele Tuominen, UmU, 1135 kSEK (2 years)
- Pre-study on biological pretreatment of softwood for bioethanol production, Shaojun Xiong, SLU, 567 kSEK (1 year)
- Karakterisering av mikrostrukturer i askpartiklar från omvandling av fosforrika restströmmar med tomografi, Mikael Thyrel, SLU, 567 kSEK (1 year)

In the 2019 call for **targeted strategic funds**, three 2 year-projects were granted:

- Fermentative production of arginine from organosolv hydrolysates for generation of arginine phosphate fertilizers, Nils Skoglund, UmU
- High resolution Silviscan and high throughput chemical analysis of wood in greenhousegrown aspen from large scale screenings using automated phenotyping, Ewa Mellerowicz, SLU
- Carbonized super-light aerogels and their characterisation and use in energy storage, Kristiina Oksman, LTU

Awards and commissions of trust, etc.

Bio4Energy researcher Nils Skoglund (Thermochemical and EnviroNut platforms) was awarded Kungl. Skytteanska Samfundet's prize for a young well-deserving researcher at Umeå University's Faculty of Science and Technology. From the jury's motivation: *"...excellent example of how applied research that investigates highly complex industrial problems can make use of the very latest top-quality, international infrastructure. Moreover, the results of his studies are highly sought after as part of the development of technology-based methods that promote a sustainable fossil-free society."*

The research by Shaojun Xiong et al. (Wood pre-processing and BioPolChem platforms) on combining mushroom production with biofuel production was selected by IVA (Royal Swedish Academy of Engineering Science) among "Årets bästa - forskning och teknik i Sverige 2019" (IVA Aktuellt Nr 6, p. 24, 2019) and was also highlighted by IVA's chief executive in IVA's annual technology speech 2019.

Bio4Energy researchers Leif Jönsson and Carlos Martín received a Highly Downloaded Article 2019 award of *Bioresource Technology* for their publication "Pretreatment of lignocellulose: Formation of inhibitory byproducts and strategies for minimizing their effects", *Bioresource Technology* 2016, 199, 103-112.

Bio4Energy's researchers also hold a large number of commissions of trust, and act as members on various boards and committees, as advisors on boards linked to national and international research councils, and as editors of scientific journals. Examples include the Scientific Council of Centre for Business and Policy Studies (SNS), the European Federation of Chemical Engineering (EFCE), IEA Bioenergy, and the working group for MWP (Marcus Wallenberg Price).

Media and outreach

Research and collaborations enabled by Bio4Energy have seen substantial outreach and visibility during 2019.

Shaojun Xiong was widely visible in media regarding the above-mentioned, cross-platform research on combined production of mushrooms and biofuels. This was covered by, e.g., Sveriges Radio Vetenskapsradion, forskning.se, Skogen, and IVA Aktuellt.

Also Bio4Energy researcher Jyri-Pekka Mikkola was very visible in media during 2019, with news about a successful process for the production of bio-based hydrocarbon. This was covered both regionally, nationally and internationally, by, e.g., Sveriges Radio, Svenska Yle, SISU Radio, TV4, SVT, as well as a number of newspapers and magazines, including Svenska Dagbladet, Västerbottens-Kuriren, Land, Bioenergitidningen, Kemivärlden Biotech and Huvudstadsbladet.

Other media impact by Bio4Energy's researchers include a reply to a debate article in DN regarding the need to broaden the support for biogas to also include gas from thermochemical conversion (Joakim Lundgren and Rikard Gebart, via SFC), and participation by Stina Jansson in both Morgonpasset P3 and TV4 Nyhetsmorgon regarding recovery of organic waste during space travels.

Bio4Energy news have also been addressed by specialist press within our sector, such as Tidningen Bioenergi, Process Nordic and ATL Lantbrukets Affärstidning. In the overall sectoral press, Altinget, Industripress and Forskning, to mention a few examples, have taken up Bio4Energy news, as well as local media. International examples include Bioenergy International, Bioenergy Insight Magazine and Canadian Biomass.

B4E graduate school

There are currently 55 active PhD students within the Bio4Energy research environment.

The Bio4Energy Graduate course "Systems perspectives on biomass resources" was held October 28th-November 1st at LTU. Ten students, both PhD students and postdocs, participated.

Several PhD students connected to Bio4Energy have defended their theses (licentiate or PhD) during 2019, including:

PhD theses

- Mirva Niinippu, Department of Chemistry UmU: "Tailoring residue-derived carbon materials for the removal of wastewater contaminants: adsorption and surface properties"
- Anders Rebbling, Department of Applied Physics and Electronics UmU: "Application of fuel design to mitigate ash related problems during combustion of biomass"
- Yngve Ögren, Energy Engineering LTU: "Improving the efficiency of entrained flow gasifiers by real time in-situ diagnostics and burner design"
- Edgar Cardenas, Chemical Engineering LTU: "Synthesis of zeolites from economic raw materials"

- Yawer Jafri, Energy Engineering LTU: “Biofuels from Kraft Black Liquor: Pilot-Scale Gasification Development and Techno-Economic Evaluation of Industrially Relevant Biofuel Production Pathway”
- Linn Berglund, Material Science LTU: “From bio-based residues to nanofibers using mechanical fibrillation for functional biomaterials”
- Kristoffer Jonsson SLU: “Understanding The Molecular Basis Of Differential Growth During Apical Hook Development”
- Ainhoa Calleja Rodríguez SLU “Quantitative Genetics and Genomic Selection of Scots pine”
- Thi Hai Hong Nguyen SLU: “Genetics, breeding and deployment of Melaleuca and Norway spruce”

Licentiate theses

- Adolf Krige, Biochemical Process Engineering LTU: “Microbial Fuel cells, applications and biofilm characterization”
- Chunyan Ma, Energy Engineering LTU: “Development of low-cost ionic liquids based technology for CO₂ separation”
- Angel David Garcia Llamas, Energy Engineering LTU: “Fast devolatilization of biomass: An experimental study using high-speed imaging, relevant for suspension firing technologies”

Meetings and events

Bio4Energy organised the webinar series Sustainable Cities and Circular Bioeconomy in collaboration with the platform Green Technology and Environmental Economics at Umeå University. Four webinars were held, with both physical audience at UmU and participants who followed the webinars via link. During the spring, Bio4Energy also participated with speakers and stand at the Energy Confusion conference in Skellefteå, as part of the constellation Bioekonomi i norr, and at BioBase 2019 in Piteå. During the autumn, notable events where Bio4Energy participated include the Advanced Biofuels Conference in Stockholm and RISE Processum’s membership meeting.

Various constellations of Bio4Energy researchers participated as organisers in the conferences Zeolite Membrane Meeting, Social Science in Our Time, the Swedish Gasification Center’s program conference, the Bio4Metal final conference and the HTC conference.

Regarding internal events, two internal researchers’ meetings were organised during 2019.

Advisory board meetings and topics

Following the start-up meeting in the autumn of 2018, a thematic workshop on biorefinery residual streams was organised during the spring 2019, as this was a topic of interest among the Advisory Board members. During the Advisory Board meeting of the autumn of 2019, focus was on Bio4Energy’s roadmap towards a new program period. The Advisory Board members gave comments in the form of responses to a questionnaire related to Bio4Energy’s future, which was discussed during the meeting. The meeting also contained two research presentations related to difficult-to-treat biomasses in biochemical conversion, and drop-in fuels based on black liquor.