Sustainable Bioenergy
Solutions for Tomorrow

About BEST

Experts from energy and forest industries joined forces in the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program. Results from the program will help improve the competitiveness of bioenergy, and the realization of new sustainable business such as large institutional investments.

The importance of bioenergy is increasing with the transition of our energy system towards renewable energy sources. At the same time, biomass is utilized in progressively more versatile ways as raw material in other applications under bioeconomy. Accordingly, the demand for biomass is growing. Therefore, the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program investigated bioenergy as part of both the energy system and the bioeconomy context and set sustainable and efficient use of biomass as a starting point for the solutions to be developed.

The research program combined the research of the forest and energy sectors more closely than ever, allowing researchers to examine bioenergy concepts, markets and the logistics of biomass supply in large entities. This joint effort strengthened the competences and international competitiveness of the Finnish bioenergy sector by building the scientific basis for new bioenergy innovations. The results of the program help raise the cost and resource efficiency of bioenergy value chains to a new level, develop concepts that are viable in the future operational environment, and ensure the sustainability of bioenergy solutions. In this report, we summarize the key research done within the program and present examples of the results.

The program began in January 2013 and ended in December 2016. 25 companies and 15 research institutes participated in the program. The total value of the research was about 15 million euros, of which corporations paid 30%, public research institutes and universities 15% and Tekes (Finnish Funding Agency for Innovation) 55%.

The research program was the first joint program of two Strategic Centers for Science, Technology and Innovation (SHOK). Of these, CLEEN brought together the companies and research communities in the energy and environmental sector, while FIBIC operated in the field of bioeconomy. In autumn 2015 CLEEN and FIBIC merged into CLIC Innovation Ltd.

Kaisu Leppänen
Program Manager
BEST Research Program

Christine Hagström-Näsi
Senior Advisor
CLIC Innovation Ltd.

Background of the research

The significance of bioenergy and other renewable energy in energy production is growing. Simultaneously, the value of biomass as a raw material in other areas of bioeconomy is increasing.

The use of renewable energy sources is increasing at an accelerating pace, as countries strive to reach global climate goals. Solar and wind energy will rise to an important role, but the total energy system cannot rely solely on them, as their production varies depending on the weather. There is a need for reliable, adjustable energy sources, i.e. energy in which production can be controlled flexibly. Bioenergy offers a solution that meets two important criteria: biomass used as fuel is renewable, and it can be stored. Also, the locality of biomass, such as logging residues, can be considered as an advantage.

"The optimal combination of bioenergy and other renewable forms of energy will be sought after strongly in the coming years. In addition, the production of bioenergy must be examined as a part of bioeconomy, not just in the energy system context," emphasizes BEST program manager Kaisu Leppänen from Spinverse Innovation Management Oy. Recent innovations promise an increasingly diverse use of biomass, e.g. as a raw material for material applications, which is expected to increase competition on biomass. At best, the various uses of biomass complement each other and the overall value will grow following the principles of sustainable development.

"It is increasingly important to ensure that all bioenergy concepts and value chains are sustainable and better than fossil energy options. Sustainability is a key objective of the international energy policies, and thus a prerequisite for bioenergy. Pioneering in sustainability can also be a competitive advantage for a company", Leppänen says.

Finnish bioenergy has a solid foundation in forests. Logging residues are harvested, chipped and transported in a cost-effective way to bio-based power plants and biorefineries, and the by-products of the wood processing industry are utilized as sources of energy. The Finnish know-how in these fields is world-class. Finland also holds an internationally leading position as a developer and utilizer of combined heat and power production.

"In addition to the strong technology and logistics know-how, we need to strengthen our ability to manage large entities, as well as increase our understanding of new operating environments, in order to create new successful concepts", Leppänen points out. She expects that the best practices for procurement, logistics and bioenergy production can also be applied in other countries, and in addition to forest biomass, also to other biomasses, which will inevitably grow in importance.

Finland's bioeconomy strategy (2014) aspires to create:

- competitive and sustainable bioeconomy solutions to global problems
- new business in both the domestic and international markets

Priorities of the Strategy:

- To create a competitive business environment for the growth of bioeconomy
- To create new bioeconomy business by means of venture financing, bold experimentation and crossing over industry borders
- To renew the knowledge base of bioeconomy by developing education and research activities
- To secure the availability of biomass, the functioning of raw-material markets, and the sustainability of biomass use

Finland's energy and climate strategy (2016) outlines concrete actions and objectives that enable Finland to a) reach the energy and climate targets set in the Government Program and by the EU by 2030, and b) continue on a consistent path towards carbon neutral society in 2050.

Bioeconomy and clean solutions in the Government Program

The Government of Finland has defined objectives related to bioeconomy and clean solutions to be achieved by 2025, by means of

spearhead projects. They include, e.g.:

- Cost-efficient carbon-free, clean and renewable energy
  - The use of emission-free, renewable energy will be increased sustainably, so that its share in the 2020s will rise to more than 50% and the self-sufficiency ratio to over 55%
- Wood on the move and new products from the forest
  - Diversifying the use of wood, and adding its use by 15 million cubic meters per year and increasing the processing value.

Participants' opinion

New perspectives on the international market

Fortum participated in the BEST program starting in the preparation phase. At that time, we had set to assess how we could produce bioenergy in the growing international market. The availability of biomass and the sustainability of its acquisition are essential questions in all markets, and answering these questions calls for a great deal of background information and local knowledge. The BEST program provided us with competent partners to do just that, and we could benefit from the experience and contacts of the researchers both in India and Poland. We were also interested in how urbanization will guide the use of bioenergy, and what would a green city be like. In the BEST program, we compared the bioenergy models of different types of Finnish and European cities. Overall, the research program provided a solid foundation on which we can build future export concepts."

Marja Englund
Manager for external research
collaboration networks
Fortum Oyj

Partners and visibility for a growth company

When a young company uses its scarce resources on collaboration, the goal is to get very concrete and useful results out of it. At Prometec, we had high expectations when we entered the BEST program during its second half, and those expectations were met. Together we could consider entities relating to biomass management in a way that would not have been possible on our own. The most important offerings of the program were good partnerships with major companies in the field. Networks are vital to a company that wants to do things differently than they have been done for the past 30 years. I believe that the cooperation will land us more business in the future."

Henna Karlsson
CTO
Prometec Oy

Results and statistics

Numerical results:

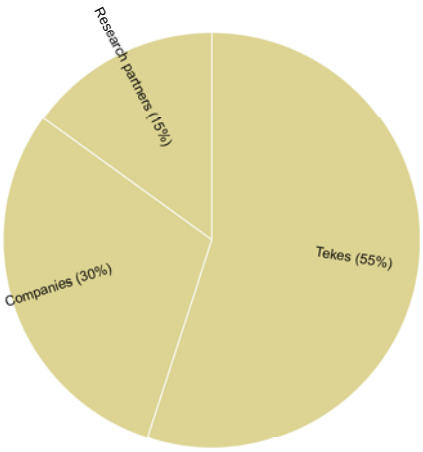
51	**peer-reviewed scientific journal articles**
48	**conference publications**
22	**theses**
107	**technical reports for industry's needs**
2	**research pilots in new markets**

As an outcome, the BEST program:

- Improved the cost and resource effectiveness of biomass
- Created knowledge and tools to promote the realization of new investments
- Built the scientific basis for new bioenergy innovations
- Analyzed the operational environment of bioenergy and changes related to it
- Deepened domestic co-operation between different industries
- Analyzed the operating environment of the bioenergy sector and changes related to it- Strengthened ties with international research programs and built an active co-operation and research network, e.g., in India and in Poland
- Helped implementing the Finnish bioeconomy and energy and climate strategies, as well as reach the objectives of the spearhead projects of the Government relating to the bioeconomy and clean solutions.

Participants

Budget (15 Meur)



Companies

- Andritz
- Arbonaut
- Ekokem
- Etelä-Savon Energia
- Fortum
- Gasum
- Helen
- Indufor
- Inray
- Mantsinen Group
- Measurepolis Development
- Metsä Group
- Metsähallitus
- Metsäteho
- MW Power
- Neste
- Pohjolan Voima
- Prometec
- Savcor
- Senfit
- Stora Enso
- UPM-Kymmene
- Valmet Automation
- Valmet Technologies
- ÅF Consult

Research partners

- Aalto University
- European Forest Institute
- Finnish Environment Institute
- Finnish Geodetic Institute
- Finnish Institute of Occupational Health
- Finnish Meteorological Institute
- Karelia University of Applied Sciences
- Lappeenranta University of Technology
- Natural Resources Institute Finland
- Tampere University of Technology
- University of Eastern Finland
- University of Helsinki
- University of Oulu
- VTT Technical Research Centre of Finland

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New markets

Finnish strong know-how in bioenergy production and utilization can unlock the bioenergy-related business potential in growing economies and develop the sector in a sustainable way. However, any new investment decisions need to be based on a detailed analysis of available policy support, resource assessment, fuel quality, supply chain logistics, feasible technology, market demand and risk management (uncertainty analysis). To enter any new market, it is imperative to understand the market development and scientific and technical challenges, analyse factors and constraints, and provide innovative and systematic solutions by optimizing the bioenergy value chain in the globally inter-connected business environment. This understanding enables making sustainable investments and simultaneously also boosting the socio-economic development in the new markets.

A Triple Helix network was developed to bring together academia, industries and research institutions from Finland, India and Poland to explore the opportunities for Finnish industry to penetrate these new markets. The BEST consortium, together with the numerous international (local) partners, analysed the key governmental and private action plans/roadmaps to develop rural-urban concepts related bioenergy and how to integrate bioenergy feedstock supply systems in those concepts, especially in India and Poland. In addition to policy, new knowledge on existing social processes and influences on feedstock supply provides the business community with a relevant synthesis for the development of bioenergy value chain in India and Poland. Importantly, findings like the low willingness of farmers to engage in biomass production reflected the present uncertain market conditions in India and Poland.

Meanwhile, there is an increasing interest in circular economy and the vital role of urban bioenergy and biomaterials in the future cities. The effects of improved resource recovery and transition into bioeconomy and circular economy on the amounts, flows, and availability of different biomaterials and bioresidues was studied in the future cities of Finland, Germany, India and Poland. The analysis presents the barriers on both technical and other (environmental, social, health related) affecting the implementation of MSW based waste-to-energy projects in the future cities.

Information on the spatial distribution of biomass resources is needed to realistically model the future power plant / biorefinery locations. Therefore, both field surveys and advanced GIS & Remote Sensing methods have been developed to map the key resources (agro, forest, and MSW) and assess the potential biomass supply for energy generation in the three selected states of India and in two selected provinces of Poland.

Although there exists a great potential of biomass resources both in India and Poland, the biggest challenge has been how to cost effectively harvest, collect, process and transport the biomass from the field to the plant gate. Given the high cost of biomass collection with low payload capacity vehicles from scattered agricultural collection points, it is imperative to improve the overall collection and transport efficiency. To achieve that, an ICT tool integrated with closed loop biomass procurement strategy was tested in Poland which could translate the existing agro biomass supply challenges into a new supply chain business opportunity.

The feasibility of Finnish CHP solutions to Indian conditions was also studied through case studies evaluating the techno-economic performance of an industrial CHP plant in different market conditions. Two case studies were conducted: Case 1 – Dedicated biomass power plant (Indian vs Western technology) and Case 2 – CHP plant co-firing coal and biomass. Results revealed that in Case 1 both Indian and Western Technologies would be unprofitable without subsidies under current market conditions. However, the Case 2 results revealed that the co-firing of biomass with domestic Indian coal can be more feasible compared to condensing power plant, and in addition coal provides the benefit of fuel security and biomass price control.

The Triple Helix model of networking developed in BEST helped utilize the inter-connectedness of R&D, business and public sectors. The model sets an example for how to take Finnish innovations beyond its border. The work also enhanced knowledge and understanding about the opportunities and challenges of doing bioenergy business in India/Poland including their characteristics in rural and urban areas of these large and highly diversified countries.

Sustainability

Sustainability is a key objective of the international energy policies, and thus a prerequisite for bioenergy. Sustainable bioenergy is actively addressed by businesses, legislation, standardisation, certification systems and research. The potential of bioenergy solutions to reduce greenhouse gas emissions in comparison to fossil energy sources has been a major driver of bioenergy and an opportunity for bioenergy business. Bioenergy business operators could justify the role of bioenergy as part of the future energy system through demonstrating these sustainability benefits inherent in bioenergy solutions and through various sustainability advancements, for example, cost savings, decreases in other harmful environmental impacts and increases in local well-being by considering both value creation and retention for different stakeholders. There is a need to further develop and clarify several issues related to the sustainability of different bioenergy solutions in different operating environments.

The BEST program addressed sustainability in the work package dedicated to enhanced business opportunities through securing sustainability. Furthermore, sustainability was an integral point of view in all the research in the program. The sustainability work package addressed all dimensions of sustainability: environmental, social and economic. The environmental sustainability research included agro-based bioenergy value chains, greenhouse gas emissions and water footprint and tools as special areas of interest. The social sustainability and acceptability research, which is often slightly overlooked in favor of the environmental studies and thus deserved a deeper look here, was further broadened by studying occupational health and safety issues in bioenergy value chains. All the sustainability dimensions were holistically considered and the sustainability research was summarized in a task that resulted in the identification and characterisation of strategic business approaches for assessing and improving overall sustainability.

The sustainability work proceeded through independent research tasks by the various partners as well as joint workshops. The workshops aimed to disseminate knowledge about best sustainability practices between Finnish bioenergy operators and internationally, to analyse the contemporary discussion on the sustainability of bioenergy systems and sustainability developments, and to acquire an extensive view of the concept and components of sustainable bioenergy systems to characterise bioenergy business approaches for sustainability.

Different aspects of sustainability are emphasised in different bioenergy solutions and locations. For example, although bioenergy chains using agrobiomass as feedstock face sustainability challenges related to competition with the food system for feedstock, land, water, nutrients etc., they are less prone to social prejudices related to image, odour emissions etc. that are associated with bioenergy chains using biowaste as feedstock. Greenhouse gas emission reductions in comparison to fossil alternatives is a major driver of bioenergy, and verification of the reduction is legally required. Other rising sustainability themes or challenges that cover all sustainability dimensions include freshwater availability, biodiversity and land use change. A variety of useful tools and methods applicable for risk and impact assessment exist and were developed further. It has been recognized during the program that being prepared and proactive in sustainability issues can be a source of growth for companies.

Overall sustainability

A holistic assessment of the overall sustainability of bioenergy systems requires simultaneous consideration of environmental, social, socio-economic and economic sustainability dimensions. Bioenergy sustainability research has traditionally concentrated on the sustainability dimensions separately. Furthermore, although the legislative sustainability criteria in the EU are a strong initiative towards sustainable biofuels, they concentrate on few sustainability aspects. Thus, the major improvement that could be achieved in improving overall sustainability is shifting from an approach of managing specific sustainability aspects to a systemic and holistic view of the bioenergy system and the capability to manage its interactions and trade-offs. Bioenergy business operators play a major role in enhancing the sustainability of bioenergy systems.

The research objectives in this work were to identify and characterise bioenergy business operators' approaches to sustainability and to identify

enhanced business opportunities through securing sustainability. The literature review and three workshops attended by bioenergy experts gave insights into the multitude of sustainability themes, criteria, indicators and methods and tools for sustainability management that the bioenergy business operators need to be capable of managing. The selected approach depends, for example, on the role of a bioenergy operator in the bioenergy production chain (e.g., biofuel producer, technology provider, bioenergy producer), and the characteristics of the bioenergy production system and challenges and opportunities in the operational environment.

The consideration of sustainability in its local context is important. Many of the environmental sustainability impacts, such as land use change, biodiversity, and water use, are primarily local, although their importance has been acknowledged also at the level of planetary boundaries. In addition to the environmental safety, at the local level bioenergy operations can be linked to the needs and well-being of the local people that determine the social foundation for sustainable bioenergy business.

Most bioenergy operators are well aware of the legislative sustainability requirements for bioenergy, achieve timely compliance, and aim to influence the development of such requirements in different locations of operation. An absence of legislative sustainability requirements emphasises the corporate responsibility for sustainability and the ability to manage local risks of environmental pollution and social or economic problems. This requires the ability to assess the potential impacts, improve the processes and to communicate the impacts and improvements to stakeholders.

Measures to improve the efficiency of bioenergy processes are a common business approach to sustainability. Bioenergy operators identify ways to improve the efficiency of bioenergy production processes to cut costs and often to simultaneously cut emissions or other harmful impacts on the environment. Stakeholders, such as customers and inhabitants of the local operational environment are interested in the impacts of bioenergy operations and are considered by bioenergy operators either reactively, e.g., by responding as such enquiries occur, or proactively, e.g. by acquiring voluntary sustainability certificates could help to demonstrate sustainability efforts for stakeholders.

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Environmental sustainability

Bioenergy business is largely driven by its potential to reduce GHG emissions and to replace fossil fuels by renewable alternatives. Bioenergy has often been considered as a carbon neutral source of energy. This is mainly based on the assumption that the carbon released during combustion of biomass is sequestered back into growing biomass, thus the atmospheric CO2 concentration is not increased due to biomass combustion. However, the urgent need to mitigate climate change has raised concerns on the carbon neutrality of bioenergy expansion due to impact biomass production and harvesting have on land ecosystem carbon stocks. Other environmental impacts such as water footprint are also important.

The **carbon neutrality** of bioenergy production appears differently in the short and long term and between various feedstocks. All this has led to the wide debate and confusions on the efficiency of bioenergy in climate change mitigation. The determination of the climate impacts of bioenergy includes assumptions that need recognition, and a systemic and holistic view of the bioenergy system and the capability to manage its interactions and trade-offs are required.

The selection of the **land and energy reference system** for bioenergy may heavily influence the climate effects of bioenergy. The selection is not a feedstock or technology specific issue, rather it depends on the question asked. The BEST research provided guidelines for how to choose the reference systems to reduce incoherencies and improve comparability between various studies. The forest-residue-based synthetic biogas production case study showed that the forest carbon stock changes due to increased biomass harvesting may significantly lower the efficiency of forest bioenergy in climate change mitigation. In addition, a significant part of the energy content of wood is often lost in the conversion of biomass to synthetic biofuels. This means that the changes in forest carbon stocks appear more significant per converted biofuel than biomass harvested.

Often, **carbon stock change** due to biomass harvesting is an issue only when the relatively long rotation biomass such as forest biomass is considered within a limited time-horizon. Instead, the carbon neutrality concept is a good approximation for short rotation agro-bioenergy. However, the agro-bioenergy case study showed that this is not always true when the reference land system is chosen coherently. Land occupation for agro-bioenergy production either displaces some other function of agricultural production resulting in indirect land-use changes or postpones the regeneration of land towards its natural state resulting in forgone carbon sequestration. The latter option is appropriate when the reference system is intended to represent no human intervention, which is the case if market-mediated effects are to be excluded.

The research that assessed agro-bioenergy production from two pathways – straw to combustion and turnip rape for biodiesel – concluded that although the agro-bioenergy production pathways reduce GHG emissions in comparison to fossil alternatives, they still consume quite high amounts of non-renewable resources. The business needs to address this controversy to better justify its cause. In addition to the climate change impacts, the most considerable **sustainability challenges and indicators of agro-bioenergy** pathways included eutrophication, soil quality, ecotoxicity, biodiversity, use of non-renewable resources, use of water, and production efficiency. These sustainability challenges can vary from production location to another. The sustainability of both pathways could be markedly improved by several options, of which the most important is optimized yield. Better distributions of manure could help to increase the amount of organic fertilizers, but also create additional costs. Soil fertility improvement (carbon stock and pH) was also identified as the important long-term goal for improving sustainability.

The BEST research shows that, although GHG emissions have long been a major research interest and their reduction is a legal requirement in the EU, challenges in their determination remain. Furthermore, the local environmental sustainability issues represent a rising area of interest. Water sustainability is currently one of the fastest developing research areas. The applicability of the existing **water sustainability tools** and methodologies for bioenergy business was therefore studied. One of the latest developments is the publication of the standard ISO 14046 Water Footprint in 2014. The development shows also in the variety of available online tools, including water stress indicator maps, risk assessment tools and water stewardship tools. The lack of methodological examples currently restricts the assessment of the water footprint. Supplemental information from a water risk assessment tool, such as the Water Risk Filter, helps to identify local reputational and regulatory water risks in addition to physical risks.

Social sustainability

Bioenergy business can have several positive and negative impacts related to a variety of social sustainability issues such as employment, training, labour conditions, health and safety impacts, investment and procurement practices, land use rights and access to resources. While the sustainability criteria of the EU Renewable Energy Directive focus primarily on environmental impacts, there are a few voluntary schemes, such as Global Reporting Initiative and Global Bioenergy Partnership, which have social sustainability as a significant component of their requirements for achieving certification. However, due to the complexity and diversity of the bioenergy sector, the guidance for bioenergy industry on how to assess non-financial issues and integrate them into Corporate Social Responsibility is not yet clear. Research regarding social sustainability in BEST focused on:

1. Social sustainability criteria of bioenergy business
2. Critical social sustainability impacts on all stages of the bioenergy supply chain

3. Social materiality assessment and communicating social sustainability impacts
4. Bioenergy conflicts and their management
5. Components of acceptability of bioenergy business

Social sustainability indicators in a variety of sustainability reporting schemes were first reviewed and a **necessary and sufficient list of social sustainability indicators** was devised, which are of relevance to Finnish bioenergy business. The interests of both stakeholders and companies were taken into consideration. A challenge is also that social sustainability often has mainly qualitative aspects. Selected categories of social sustainability criteria have been supplemented with their minimum requirements in relation to bioenergy sector specific needs.

A challenge in the social sustainability assessment is that social and environmental impacts of bioenergy systems are considerably higher upstream, whilst the economic value added happens at the last stages of the value chain. It is recommended that companies conduct **social sustainability materiality assessment** to assess critical social sustainability impacts in all stages of the value chain. The research also pointed out the dilemma of how to deal with social sustainability issues, especially upstream on the value chain, on which the company has no influence on. Attention is also needed on how to communicate sustainability issues, positive or negative, to stakeholders. It has been recognized that sustainability reporting and stakeholder engagement must be incorporated into corporate strategy and performance evaluation in the future with the adoption of new frameworks promoting greater corporate responsibility, accountability and transparency.

Any field based on the use of natural resources is bound to face different **resource use conflicts** due to increasing demand and simultaneously occurring deterioration of resources. The produced report on resource use conflicts offers insights for bioenergy businesses in the identification and management of conflicts, i.e. differences in opinion, serious disagreements, clashes of interest, and public protests. The specific aim was to help companies identify and manage conflicts at a stage when the conflicts do not yet threaten their operations. **Social acceptance**, a good understanding and strong support of bioenergy by the general public, is also an essential driver for the diffusion of bioenergy technologies. Social acceptance of bioenergy is shaped by many factors, e.g. biomass type, conversion technology, end-use sector, size of production facilities and geographical region. Assessment of social acceptance of bioenergy was conducted for forest biomass and industrial residues, forest plantations, municipal solid waste and agricultural biomass. The study focused on finding the most important components of social acceptance for each element of these value chains, including consumers, investors and intra-company views. The three dimension of social acceptance; socio-political, community and market acceptance; and the main issues within these in bioenergy value chains were assessed. The study concludes that the availability of information and sufficient communication process with the main stakeholders, enhanced sustainability of bioenergy, competitiveness of the bioenergy industry in relation to other industries and sectors, as well as a reliable political framework conditions are the main factors shaping the social acceptance of bioenergy.

Occupational health and safety

The use of bioenergy has increased during the last decade, and there are ambitious targets to increase the use of solid biofuels furthermore. The number of employees working with bioenergy is therefore expected to grow, making it increasingly important to learn about the bioenergy production processes and the health and safety issues involved in the biomass supply chain. The exposure of people living near heat and power plants may also grow.

The aim of the health and safety studies carried out in BEST-program was to clarify the health and safety issues in the beginning of bioenergy supply chains prior to energy production and to create recommendations for best practices during handling, storing and transportation. The study covered the chain from forest to power plant focusing on operations and storage in terminals, as well as the storage and use of future advanced densified bio-products prior to co-firing in urban environment. Particularly, the aim was to analyze the exposure to different emissions of fuels used at power plants sites and their ashes. The goal was also to develop guidelines for safe delivery and handling of solid biofuels at existing power plants and new power plants to be constructed.

Literature reviews and experimental measurements at different parts of bioenergy supply chain were conducted to answer the following central research questions:

- What are the general health and safety issues during handling, storing and transportation of solid biofuels?
- What are the health and safety risks associated with storage and use of densified biofuels in urban environment?
- What are the technical means to diminish the possible exposure during storage and terminal operations?
- How to avoid spreading of dust and odor gases to the surroundings?

The main occupational exposure associated health risks for workers were found to be bacteria and fungi, which are easily spread to the air during the operations at biomass terminal sites and at power plants. The measured exposure levels of endotoxin, bacteria, actinobacteria and fungi were high especially in fuel reception. In addition, workers are exposed to mechanical irritation caused by organic dust and chemical irritation caused by VOCs and components of diesel exhausts. Multiple exposure to these agents simultaneously may cause synergistic health effect on workers' lower and upper respiratory tract. Significant health issues related to wood pellets include dusting and off-gassing. Truck drivers and power plants workers can also be exposed to ash during loading, especially in closed loading stations. It also seems that some heavy metals are enriched in respirable fly ash particle fraction.

The key factor in preventing exposure associated respiratory impairment of workers at the biomass fueled power plant sites is to improve the quality of fuels. The solid biomass fuel quality is dependent on the different steps of the whole supply chain. Microbial growth and microbial contamination in fuels can be prevented by strict control of temperature, moisture content and storage time. The better microbial quality ensures also higher energy content of solid biofuel. All valuable preventive technical measures should be taken on use to keep the occupational exposure as low as possible. Isolation of the spaces e.g. by closing doors in the fuel reception halls and use of hoods around the crushers and screens, reduces spreading of bioaerosols and other agents to the workers' breathing zone. Over pressurized control rooms for supervision of unloading of fuel trucks, automated fuel sampling and automatic cleaning systems for fuel trucks are favorable solutions to reduce exposure of truck drivers. The exposure to ash can be prevented by optimizing the moistening process of ash, using of tank trucks instead of open cassette flatbed trucks, and by sealing the loading line from ash silo to the truck. Personal protective equipment has to be used If technical measures are not efficient enough to reduce the exposure.

Concepts and systems

Bioenergy is always linked to larger systems – it is a part of the energy system as well as bioeconomy, where biomass is utilized for various end products. Bioenergy must find its competitive role and benefits in these future frameworks to ensure the optimal use of biomass resources and sustainable, efficient and reliable energy production. Bioenergy concepts are also applied in different environments, including urban settings, rural areas and industrial systems. As urbanization progresses, the most likely future application environment for bioenergy is a big city. Future cities are expected to combine various approaches, i.e. improved energy efficiency, increased recycling and closed loop systems, smart energy systems, and implementation of other renewable energy technologies besides bioenergy. What is the role of bioenergy in this context, and what kind of biomass flows are available?

The objective of this research was to create and study and create concepts for:

- Integration of bioenergy and other renewable energy production
- Energy storage based on biomass and bioproducts
- Viable bioenergy concepts operated in parallel with other biomass-based production
- Bioenergy systems and biorefineries for urban areas
- Novel integrated industrial bioenergy concepts

- New business models and ecosystems per future needs

Using the research results and visions generated during the program, various bioenergy cases such as biomass terminals, ICT tools for bioenergy value chains and new urban biogas ecosystems were analyzed as value networks to find new business from evolving technologies and markets. The viability of different business concepts in the future bioeconomy framework was also analyzed. The best and most successful future bioenergy concepts are likely to be case-specific instead of universal and unambiguous value chains. Circular uses of waste streams to energy, nutrients and chemicals especially can lead to diverse, and often smaller process alternatives. Evolving cities can offer interesting opportunities for such circular value chains. A successful bioenergy concept will make use of domestic technology and raw materials, thus generating positive effects on both regional and national economy.

Please see the subtopics for more information on bioenergy in the city, energy system and bioeconomy contexts, and the studies related to quell properties and combustibility and pyrolysis behaviour modelling.

Several industrial integrated concepts were also created and assessed. Studying 1) the integration of biomass torrefaction with a CHP plant and 2) conceptual design for utilizing off-gas from metallurgical processes together with biomass-based gasification in a gas turbine in power production showed that in certain conditions these integrated concepts can be profitable compared to standalone plants. The results can also be exploited in similar conceptual studies by changing the initial data. The second concept is the first of its kind and there are good opportunities for multiplying it. In addition, a unique concept for processing of industrial side or waste streams together with saw dust to a more valuable fuel produced was created. Thus, low value side or waste streams (saw dust, sludge, soot) can be converted in a specific dryer into viable (higher caloric value) biofuels. Implementing the concept will help reduce both heavy oil consumption and emissions at power plants. The concept can also be replicated for different kinds of side and waste streams.

Urban bioenergy

The increased population and growing economy create new challenges in transition economies. The urbanization is expected to continue in the upcoming decades, increasing the total energy demand and peak demand of energy. New energy solutions play key role for tackling the challenges both related to energy production and sustainability. In the future distributed energy production, e.g. from urban waste and/or agricultural biomasses, will be in an important role. In this context biomass producers include sub-urban communities and various countryside actors such as farms and rural companies.

The BEST program studied these essential research questions to assess the role and opportunities of bioenergy in the city context:

- What are the expected biomaterial flows in the future cities?
- What is the optimal role of various bioenergy technologies and feedstocks in different types of future cities and how can bioenergy systems be designed and integrated in them?
- What are the opportunities to produce biogas in urban residential areas?
- How to integrate waste and wastewater systems and nutrient recycling in gas production systems?
- How could biorefineries and food factories be developed and integrated into urban environment?
- What is the role of communal planning in enabling the bioenergy and nutrient cycling concepts?
- How do the different technology alternatives differ from sustainability and economical point of view?

The first step was to assess the potential role of various bioenergy technologies and the availability of various feedstocks in the future urban environments. For that purpose, the climate and sustainability targets and roadmaps of various forerunner cities were used to form scenarios for the future implementation of different bioenergy technologies. Also, the potential of rural biomasses in energy production was evaluated. In all the ten studied Finnish and German forerunner cities, biogas technology for organic waste utilization was included while the expected role of other bioenergy technologies, e.g. combustion dependent on various local factors. As a second step the technical solutions and concepts to produce biogas in urban environment were evaluated using a 10 000-habitat urban residential area as an example. The objective was to calculate technical potential of decentralized circular system for residential area. Furthermore, the aim was to find out the preconditions for implementation of such systems. Another objective was to evaluate the potential of non-wood biomass to produce high value products instead of energy. The question was studied through example cases of biowaste and carrot side streams.

The findings show examples of how to integrate rural and urban systems to allow efficient and sustainable use of bio-based resources. Together with existing food systems, urban processes can form an integrated energy and material system between cities and surrounding rural areas, which also circulates nutrients efficiently. The created understanding shows the importance of nutrient recycling. It was also concluded that possibilities to utilize the biomasses are wide and the role of biomass can improve in the future when new processing technologies become more efficient and costs are reduced.

Biogas production in new urban residential areas is an interesting concept involving public and private stakeholders in a completely new business ecosystem. In the conventional linear urban metabolism, grey water and sewage waste from toilets are directed to centralized communal waste water management for purification and discharge, while biowaste is collected for composting or biogas production. Transition towards more circular use of the sewage and biogenic waste streams of residential areas was studied in BEST. Redesigning a separate collection system for the waste streams, grey waters could be reused for non-potable purposes after heat-recovery. Furthermore, nutrients in urine could be used in city farming. Biowaste from residential housing and local industries along with rest of the urine and feces would be directed to biogas production, fueling part of local transport fleet, and heat boilers and kitchen stoves and providing fertilizers to local farming. The new business ecosystem would cause demand for technology providers, new usages and processing services for grey water, and significant need for expert communication and consulting to change the status-quo of housing production and consumer behavior.

Bioenergy in bioeconomy & the energy system

Increasing renewable energy production brings variations to electricity production, and due to the intermittency of wind and solar production, calls for new energy storage solutions. Bioenergy production has the capability of adjusting to rapid changes in load and can also provide energy storage options. To make the most of these opportunities, it is important to understand how bioenergy could be optimally integrated into the future (renewable) energy system. What are the best choices in short and long term? On the other hand, it is expected that the use of biomass will diversify into a variety of different end products (materials, chemicals etc.). This shift towards bioeconomy will also increase demand of biomass. Hence, it is increasingly important that the available resources are used to produce the maximum value in a resource efficient way. Bioeconomy challenges current business models, but on the other hand creates new opportunities. It is critical to understand the optimal role of bioenergy in bioeconomy so that the different uses would be complementary rather than competing.

Bioenergy potential in electricity reserve power markets was analyzed with a simulation model built on bioenergy-based combined heat and power production. In the case of a CHP system, the heat network can be used as energy storage to provide an opportunity to control the electricity output, and thus, to operate in reserve power market to maintain the system frequency and power balance. The results indicate that the power system contain significant amount of CHP plants to be able to participate in electrical system frequency control with rather small upgrades. The results show that participation in reserve markets provides significant potential to increase profitability of bio energy based CHP.

BEST tackled the question of bioenergy in bioeconomy by defining bioenergy business concepts and studying their viability in the future bioeconomy. This also included defining and analyzing current and future regulatory frameworks with potential implications to bioenergy in bioeconomy and providing long-term bioeconomy visions based on key enabling technologies. Along with the existing policies for promotion of renewable energy, the more uncertain future regulatory developments in requirements of sustainability, circular material use (the cascading principle), and inclusion of land use and forestry (LULUCF)-sector in national emission reduction targets were considered. The purpose was to

point out the future prerequisites for successful bioenergy concepts in bioeconomy. Three case settings were chosen for extensive studies.

Concepts that exploit waste biomass even better than before did well in the anticipated future environment, as expected. The concept where waste from food production and municipal waste was processed into biochemicals and, as a side product, into energy products such as biogas, was especially promising. The concept that utilizes wood and agro-biomass was viable when it was assumed that the raw materials are side streams from other processes. This concept, in which the biomass is gasified and the synthesis gas fermented into liquid biofuels, benefits from existing sustainability criteria for biofuels and the flexibility regarding the used raw material. The use of forest raw materials was the key question in the third concept, where options to produce biofuels or energy were compared with a modern pulp producing bioproduct mill in forest industry. A biorefinery producing both bioproducts and bioenergy can in the best circumstance offer the highest added value and most efficient use of the raw materials.

The best and most successful bioenergy concepts in the future bioeconomy are likely to be case-specific instead of universal and unambiguous value chains. Circular uses of waste streams to energy, nutrients and chemicals especially can lead to diverse, and often smaller process alternatives. Evolving cities can offer interesting opportunities for such circular value chains. A successful Finnish bioenergy concept will make use of domestic technology and raw materials, thus generating positive effects on both regional and national economy.

Sustainable production of bioenergy, -chemicals and -fuels requires traceability throughout the value chain and sustainably managed bioresources. Utilization of non-recyclable wastes in energy conversion effectively reduces negative effects on the circular use of biomasses and on the carbon stocks, especially considering policy developments in the LULUCF-sector. Non-carbon stock raw materials such as straw and manure with limited competing uses should always be considered.

The chosen conversion technology should enable flexible use of different raw materials and have a high conversion efficiency of biogenic carbon to various energy products. In this regard, gasification is a key enabling technology. Finally, existing product infrastructure and standards are important factors which facilitate the economic success of any value chain.

Combustibility & Flow Modelling

By 2020, the primary solid biomass use is expected to reach 146 – 158 Mtoe while the production is only 120 Mtoe. This equates to a supply gap of 25 – 40 Mto. To meet the target, not only production capacity expansion is required but utilization of new and often challenging solid biomass must also be explored. Moreover, before the profitability of using these challenging biomasses can be determined, they must be characterized and their combustion behaviour understood.

Tampere University of Technology (TUT) concentrated on **experimental and numerical biomass fuel characterization**. The goal was to obtain experimental information on the energy-related properties of different biomass fuels, and to enhance the biomass pyrolysis and combustion modelling capabilities. These objectives can provide valuable help for the design process of biomass energy conversion technologies, such as pyrolysis reactors and power plant boilers. The experimental work included two main stages, namely, determining the pyrolysis and char combustion rates with a Drop-Tube Reactor (DTR), and evaluating the physical fuel properties via e.g. density and spherical equivalent diameter measurements. The experimental data was further used for optimizing the kinetic parameters for numerical **biomass pyrolysis and combustion models**.

Two biomass fuels, a domestic wood pellet and an Asian residual biomass pellet, were examined in two Master's theses. In the first thesis, the reactivity of the fuels was measured in the DTR and the physical fuel properties were analysed with multiple other experiments. This experimental data was then used for optimizing the kinetic parameters for numerical pyrolysis and combustion models. The second thesis was responsible for the numerical modelling. The functioning of the pyrolysis and combustion kinetics, which were optimized in the first thesis, was verified in a Computational Fluid Dynamics (CFD) model of the DTR. After this, the kinetics were further tested in a larger scale CFD simulation of a 50 kW pulverized fuel test reactor. The larger scale modelling was conducted at the Technical University of Dresden (TUD) during a three-month research visit. Together the two theses succeeded in developing an accurate optimization method that can be used for determining the pyrolysis and combustion properties of new biomass fuels. In the future, the method can be valuable especially when new and more challenging biomass sources are to be utilized in pyrolysis and combustion plants.

TUT's Polish partner, the Silesian University of Technology (SUT) studied slow and fast pyrolysis of biomass, using both the Thermogravimetric Analyzer (TGA) at SUT and the DTR at TUT. Two agricultural waste samples (wheat straw and rape straw) were processed in different pyrolysis conditions. The influence of heating rate on mass loss, pyrolysis rate as well as on the pyrolysis product yield was analyzed. The increase in heating rate resulted in shifting of start and end of the devolatilization towards higher temperatures. This effect was more noticeable during slow pyrolysis in TGA than during fast pyrolysis in DTR. The maximum value of DTG increased with increasing heating rate. The difference between volatile yields from slow and fast pyrolysis was significant for both samples.

In the **combustibility behaviour** studies, the goal was to develop competences in understanding emission formation, ash chemistry issues related to fouling and corrosion in the combustion of an agro-waste fuels. The created knowledge can be utilized to maximize the share of agro fuels in power production. Empty fruit bunch (EFB) pellet originating from the ASEAN area was co-combusted with coal. The research methods included a pilot scale test run combined with emission and ash chemistry monitoring as well as chemical modelling. The results suggest that EFB can be co-fired with this model together with coal up to around 25 en. % without risks of chlorine-induced corrosion. At this share, the required SO2 emission limits can be met by limestone addition. To realize the potential of EFB for energy production, long duration test with higher EFB en. % share must be made to assess applicability of the biofuel in large-scale combustion set-up.

Raw materials

The planning of a new bioenergy value chain begins with securing the supply of the needed raw materials, whether they come from the forest, field, or as side or waste streams from another process. What is the raw material potential in the relevant area, how much of it is sustainably available, and how can raw materials be mobilized efficiently and cost-effectively?

The work began with a synthesis on biomass availability in relevant geographical markets. Both forest based and agriculture based resources were studied. A special research effort was conducted on airborne laser scanning (ALS) technology for forest biomass applications. The objective was to develop a cost-efficient method (few tens of cents per hectare) for mapping and monitoring forest bioenergy potential (m3/ha) in the plot and stand levels. The new ALS technology enables an accurate and efficient way of collecting information on biomass volumes and location. The results create a platform that serves as a basis for cost efficient biomass sourcing for any industry or company using forest biomass as a feedstock. It can provide information that is crucial in deciding whether to select a site for harvesting and if yes, how to organize the harvesting and transportation at maximum cost efficiency.

Regarding the agro-based raw materials, in addition to the utilization of side streams like straw, the production potential of novel and old bioenergy crops were compared with short rotation coppice plants on abandoned peat production sites. To address the problem of preservation and year-round supply of agri-biomasses, evaluation of collection and pre-treatment technologies was combined with research on preservation and storage methods for optimizing the maximal yield of bioenergy carrier material. This included development of harvest and storage methods to prevent decay and moulding and studies of different kinds of wrapping methods and estimation of their costs. The fields that are not needed for food production could also be used for cultivating energy crops. Promising crops include Igniscum, Virginian malva and Sida.

On the forest raw materials side, management alternatives of peatland forests for cost-efficient and profitable biomass production were studied. An assessment of the impacts of management activities produced from the viewpoints of raw material quantity and quality, sustainability and

environmental impacts was also made. The results are summarized in the report Synthesis report on utilization of peatland forests for biomass production. Moreover, another research theme was to create better methods for baling whole trees and develop efficient harvesting models for first thinnings. The new Fixteri FX15a baler Also, the developed new robust harvesting method for multi-tree handling increased the productivity and put less strain on the driver.

Please see **Concepts and systems (/content/concepts-and-systems)** for studies regarding raw materials in the city context, and look at **New Markets (/content/new-markets)** to see how raw material availability was assessed in new markets.

Business environment

Understanding the future operational environment of bioenergy, which has been undergoing rapid changes and increasing uncertainties in the recent years, was one of the central research needs shared by the whole BEST consortium. To companies, it is vital to be able to succeed in all kinds of market situations. The business opportunities of the bioenergy sector depend on its capability to adapt to the changes in the operational environment – or, in the best case, even being able to affect the development. Although the Finnish bioenergy sector was considered to be in a strong, leading position, several issues made the future global bioenergy business environment seem uncertain. The current regulation and subsidy scheme in Europe supports the energy use of biomass, at the expense of other uses (e.g. chemicals, materials), but this might change soon. Some partners were concerned with land use issues, or the consideration of biogenic carbon in the emission calculations. The significant growth in the deployment of solar and wind energy had been noted.

The BEST program tackled the major change factors in the business environment with various tools to answer these central research questions:

- What are the main drivers affecting demand, supply and technical development of bio-based energy in its various forms and how are they expected to evolve?
- What are the main uncertainties, challenges and opportunities for a favorable bioenergy business environment from the Finnish perspective?
- What is the role of bioenergy in its various forms in the future energy systems?
- What are the long-term visions regarding bioeconomy and what is the role of bioenergy in it?
- What are the strengths and possibilities of Finnish bioenergy knowledge and technologies in the future?

The first step in the research was to make a systematic and critical review of the existing global, EU level and Nordic scenarios and foresight studies and tools on the future demand and supply of biomass and bioenergy, and of the political, societal, economic and technical drivers affecting it. Horizon scanning was deemed a useful strategic planning tool that can help identify and predict potential societal challenges in time. Assessment of EU-level scenarios concluded that the expected biomass demand exceeds the estimated available biomass potential in the EU. Therefore, several solutions are needed to improve the efficiency of biomass use. Recommended actions include e.g. improving the efficiency of European plants by replacing electricity-only plants with CHP.

The whole BEST consortium with companies in a leading role also participated in building and analyzing scenarios describing possible paths for bioenergy, spanning until 2033. The scenarios assessed the operational environment and concluded the necessary actions and development needs in each case – as well as in any case. Recommended actions that need to be carried out regardless of the future scenario include e.g. the creating a reliable monitoring system for key beacons of global development, active and collaborative development of international standards for sustainable bioproducts, supporting consortia and agile piloting, and focusing the limited research and development resources to the most beneficial and strategically important topics instead of spreading them too broadly and thinly.

The findings of the scenario work were also used to steer the research of the last two years of the program. During that phase, specific work packages were dedicated to studying a) the opportunities of bioenergy in the future energy system, and b) the optimal role of bioenergy in the bioeconomy framework. The bioeconomy framework studies concentrated on three major topics:

1. Obligations on the cascading use of wood based biofuel in the future (the limitations regarding wood fuel use merely on the wood waste material)
2. Monitoring obligations of CO2 emissions from wood fuel combustion in relation to ETS and their emission balance regulation in the wood biomass source countries
3. LCA sustainability criteria and source of origin regulation scheme expansion to all solid biomass fuels and other bioproducts.

The created understanding of the future preconditions for successful business was used to support the creation of new bioenergy cases, business models and ecosystems (see **Concepts and systems (/content/concepts-and-systems)**). Assessing how and in which conditions a specific concept could be economically viable is becoming more and more important as the role of subsidies is expected to diminish. It was also concluded that waiting cannot be a strategy – the bioenergy sector needs to proactively create its own future.

Supply chains

The variable costs, mostly the feedstock costs, play an important role for the competitiveness of bioenergy compared to other renewable energy sources. Also, in the future bioeconomy the use of biomass is expected to diversify into a wide variety of end products (materials, chemicals) to replace fossil-based ones. This will lead to increased demand for biomass. Hence, it is important the available resources are used efficiently and sustainably. It has been estimated that up to two thirds of the costs in the bioenergy value chain, for example in CHP energy production, have been created when the fuel reaches the plant gate. Therefore, radical improvements in the resource and cost efficiency as well as flexibility in biomass sourcing will benefit all bioenergy and bioeconomy value chains.

The most important result in this theme has been the unprecedented capability to evaluate and build holistic supply chain models based on simulation and calculation. The resource efficiency is brought to a whole new level when the supply chain is steered based on value. The value-based management combines e.g. accurate and real-time information on raw material quality and quantity, the production needs and parameters of the final user (e.g. power plant) and the tools for managing all the information related to the supply chain. Alternative supply chain and logistics concepts can be evaluated with simulation and modelling and the operations of the supply chain managed with modern Enterprise Resource Planning (ERP) systems.

Already over 40% of forest energy biomass is supplied through terminals and they usually increase mill-gate costs 12-22%. They can pay back in the supply, but no without careful planning and fitting to the operational environment. Simulation is an excellent way to foresee the reality before expensive investments. BEST produced several simulation models and approaches to study especially transportation and terminal options. Please see **Terminals (/content/supply-chains/terminals)** and **Logistics (/content/supply-chains/logistics)** for more information. The simulation and terminal concept results have already been utilized by companies in planning new investments and raw material procurement. In addition, e.g. the harvesting work models, solutions for lifting stumps and results from the Mekrijärvi drying park have been developed further by company projects and implemented as companies' own solutions.

As a novel operating model, the "Fast Track" supply chain minimizes the capital and raw material losses that can occur during storage by reallocating the supply of biomass for energy in a completely new way. The created direct supply chain operating models will greatly improve the resource and cost efficiency of all kinds of bioenergy solutions. Cutting down the material losses occurring during supply chains by even a few % would bring savings worth millions each year. Another alternative operation model to the terminal-based supply chains is so-called precision supply, where the roadside storages are allocated based on moisture content, storage size and transportation distance, and the best storages are utilized at the time of the demand peaks. This way the same plant can produce up to 20-30% more energy during peak demand in the wintertime.

The value and quality of the fuel can be determined by next generation smart measurement and forecasting methods such as soft sensor methods, 3D-measurements, wireless sensors, X-ray, NIR, NMR and forecast models that utilize weather data. The X-ray measurement solution, which was the result of research done on stumps and analyzing amounts of foreign matter in the fuel, has already been implemented commercially. Quality data and all other relevant supply chain information are important inputs in the value-based management, which is enabled also by standardized data transfer models and information management platforms that link. all actors along the biomass value chain.

Quality measurements and forecasting

Quality in biomass supply is a combination of the raw material, logistics and storage as well as processing technology. The quality of the raw materials can get better or worse during transportation and storage, depending on several factors, and can result to losses in its value. Accurate, efficient and affordable quality and quantity measurements as well as clever forecasting methods are needed to manage and optimize the fuel quality. In this program, several measurement technologies and systems as well as prediction models and estimation methods were studied for this challenge. In addition, sampling issues were also tackled, since sampling has a big effect on measurement system costs and creates most of the measurement errors and reliability problems.

Measurement and estimation methods for the moisture content of the raw material, load volume measurements and calculation methods of energy content (MWh) for real-time control of the heat value in the supply chain were evaluated and further developed. The MWh Roadmap prepared in the program by Metsäteho Ltd. and Measurepolis Development Ltd. introduces present supply chains for small size stem wood, logging residues and stumps and their proportions. It also presents current usable measuring methods and measurement needs at different stages of the supply chain as well as potential methods for the future terminal concepts.

Moisture is the most important quality parameter of the biomass fuel, strongly influencing its heating value and consequently the price. Fast and reliable methods for moisture determination are therefore very valuable. **Moisture measurements** based on IR/NIR, microwaves, X-rays or NMR technology were evaluated in the program and best practices were selected for the use in terminal applications. Microwave-based moisture instruments developed by Senfit Ltd. have good correlation to Loss-on-Drying (LoD) reference when calibration and measurement samples are both between 15-70%mc and the samples are from the same supply location (e.g. forest stand). The device must be calibrated separately for each fuel fraction. Inray Ltd. developed the basis for an online x-ray scanning device for biofuel enabling more accurate fuel quality data for process control and fuel trade. The system analyses in real-time moisture, foreign matter content and calculates energy content for the whole batch. On-line NIR-spectroscopy measurement of biomass moisture e.g. on conveyer belts before fuel inputs of boilers by VTT can now be developed to be more precise in different operation conditions such as cold winter temperatures.

The **volume of the load** is also important since, if the volume can be measured accurately, the value of the load can be determined more reliably. The target was to develop and test new inexpensive volume measuring methods utilizing structured light and photogrammetry for wood chip load inside the truck container. Two different approaches were studied and evaluated for volume determination by Luke. Structured light approach with the Kinect sensor worked relatively well but there were some drawbacks in the technology such as an effect of direct sunlight, which overexposures the target and hinders the reconstruction. The second approach based on photogrammetry seemed to be very promising for the studied purposes. Images can be taken from a moving vehicle or from different locations around the target. The method is also fast enough for the real environment use.

An operating model and concept for the efficient **quality control** for wood based biomass, approved by both biomass suppliers and end-users, was developed by Prometec Solutions Ltd. In the concept the quality of all incoming and outgoing raw material is monitored and the truck specific quality information is utilized for the supply chain management and control.

Regarding the **estimation and forecasting methods**, the focus was in drying and dry matter losses during storing. In storing the time spent in storage, raw materials, storage quality and the seasons of the year were monitored together. The weather during storing is very important factor to be followed, because temperature, precipitation and relative humidity of air have impact on drying and dry matter loss processes. Due to digitalization, weather data is available in Finland and in most places of Europe everywhere and data can be downloaded from the server and used for further calculations. In BEST the connection between measurable parameters like moisture content change and dry matter losses and weather history were studied. This was done using special purpose built equipment in the drying park of Mekrijärvi Research Station. The results were implemented in the form of moisture content forecasting functions, which can be used as a part of enterprise resource planning software or corresponding applications. The same applications can be used also for estimating dry matter losses or capital costs of storing.

Logistics

Biomass logistics takes place between the controlled industrial environment and the more instable natural environment. The complexity of systems analysis has increased steadily when more biomass assortments, transport and processing modes, and ways to use the biomass have been adapted in recent years.

When the BEST programme was launched, most the research about biomass logistics done so far was based on static analysis or optimization models, where biomass resource data was connected to the transportation network and, accordingly, to the feedstock demand by the end-users of the logistics chain. The static approach meant that the systems were usually analyzed on a yearly basis without any deeper insights on the system performance at different times of its lifespan. An ambitious aim to enhance the efficiency of biomass terminals, and the demand for more effective and more sustainable terminal concepts, created the need for a closer consideration of the temporal factors affecting the system balance.

Simulation modelling was found to be a suitable approach because, besides its dynamic features, it accounted for stochasticity, which is essential when the study objects are liable to random variation in practice as well. As the main outcome, the research based on the selected methodology produced:

- increased understanding about complex biomass supply systems among energy companies aiming at change from fossil to biomass feedstock
- simulation applications for finding the critical bottlenecks in logistics systems and assessing the suitability of potential logistical solutions in the future
- evaluation of different terminal concepts in relation to the total performance of the supply system
- advanced system validation and verification possibilities by simulation runs visualized in a geographical information systems (GIS) environment

In addition, various solutions for improving the cost and resource efficiency of forest biomass transport and logistics were studied.

To ensure the credibility of simulation results, much attention was paid on the availability and up-to-dateness of source data. Therefore, following important actions were included in the work:

- synchronizing availability estimates of forest, agriculture and community-based biomass from different data sources into one supply point network of high spatial resolution
- forecasting the development of transport fleet's properties
- studying and developing new operational methods in biomass handling inside and outside the terminal hub, and in transportation, especially on long distances

The main conclusion was that a dynamic modelling environment works at its best as a "virtual test bench" for future concepts, excluding all

economic risks that are present in real-world trials. However, the method is largely dependent on real-life experiences and it requires plenty of qualified source data especially for complicated scenarios. Digitalization, increasing computing capacity and availability of open data create opportunities for increasing the adaptation of dynamic modelling methods in the future.

Biomass terminals

If solid biomass fuel demand increases, as it currently seems, new logistical solutions are needed because new bioenergy capacity is built in densely populated areas while untapped raw material sources exist in rural areas. Most of the increase in use is expected to take place in large heat and power productions units which set special requirements for the supply as both procurement volumes and transport distances increase. Biomass fuel terminals broaden the spectrum of available supply options by offering cost-effective large-scale biomass storage and processing options for securing the fuel supply in all conditions.

The terminal offers security of supply for a fuel user: it can also even out fuel quality fluctuation and, by utilising terminal supply, wood fuel harvesting season and utilization of production machinery heavily burdened by high investment costs can be distributed more evenly over the traditionally quieter seasons. During the peak load the focus is on the easily accessible terminal storage facilities. On the other hand, it is obvious that additional handling and storage times add costs to supplied wood fuel compared to direct supply chains. These costs are partly balanced by savings created by more economical material handling in terminals, energy content increment during storage and more efficient logistical solutions in transportation. For example, it was concluded that comminution costs alone can be reduced to 1/3 of current average costs with right technological solutions.

The BEST program studied different biomass terminal alternatives and aimed to find solutions for more economical terminal concepts in the future. Some of the key questions were:

- What kind of biomass terminals and terminal-based supply chains exist? (Case Finland and Sweden)
- What are the volumes of biomass supplied through terminals and what are the terminal supply chain costs compared to direct supply costs?
- What are the terminal operation costs?
- What kind of infrastructure exists in terminals and what are the most cost-effective technologies and machines for more economical terminal operations?
- What characteristics will the future terminal concepts have?

In many ways Finland and Sweden are similar as far as forestry and bioenergy concepts are concerned. Both countries are the world leaders in supplying woody biomass and using it for energy production. However, there are some characteristics and differences that both countries can learn from. Therefore, biomass terminals in Finland and Sweden were surveyed and localized and the main characteristics were compared.

Biomass terminals have an important role in balancing supply and demand of solid biomass. Over 200 biomass terminals exist in Finland. Already over 40% of energy biomass is supplied through terminals and they usually increase mill-gate costs 12-22%. They can pay back in the supply, but no without careful planning and fitting to the operational environment. With a suitable location and functions, terminals can increase the efficiency of fuel logistics. In fact, terminals with high volumes and cost-effective operations do not necessarily cause extra costs to the supply chain but can instead, in some occasions, be more economical than traditional direct biomass supply chains. On the other hand, all benefits gained by terminals, such as security of supply, are not easily quantifiable.

Extensive terminal field studies were conducted to gather information from well-operating terminals on their machinery, logistics and infrastructure. Based on the survey, work studies and cost analysis of different terminal functions, supply costs of woody biomass through terminals were defined. Finally, the most effective terminal supply chains were compared with direct supply chains from forest to plant. The results of this study can be used to determine what machines and concepts could be used in biomass terminals at different supply volume levels in the future and compare their costs with traditional direct supply chains.

The proposed future ecosystems are based on creation of more efficient terminals rather than increasing the number of facilities. Conventional terminals operate as stocks of biomass fuel, raw biomass or as facilities that produce solid biofuels. The future opportunities and requirements at terminals include better automation and quality control, handling of biomass for other purpose than energy use and pretreatment of biomass. These functions generate possibilities for third party services at the terminal sites. Efficient pretreatment and refining of raw biomass at the terminal can create important financial benefit and cover costs caused by the terminal infrastructure.

Information management

ICT is a key tool in enabling the efficient management of biomass supply chains. Information technology has been studied in BEST in the context of logistics, quality management and equal access to data, considering the evolving and heterogenic user environment and the need to manage heterogeneous biomass flows for multi-fuel power plants. One of the goals of the program was to create a concept for an advanced, dynamic and open information management platform with various end-user applications. Making the disconnected data systems used by different players in the supply chain compatible is a key long-term target. A holistic data system linking all actors along the biomass value chain would form a so-called virtual biomass terminal.

A more general aim was to provide equal access to data. For example, the capability of agricultural biomass producers to participate in digital ecosystems varies a lot especially in transitional economies. Therefore, there was a need to study how biomass producers can act as end users in a digital ecosystem and use different means to access information. The means of access are not limited only to what kind of internet-capable devices the users own, but must also cover means how users without their own devices can participate in the ecosystem.

The work began by studying the information management needs and solutions in different types of biomass supply chains and then defining the needed data and information flows, requirements for data content, functionalities, and data transfer principles for the virtual terminal. A common data model was designed to be used for both the virtual terminal and, more generally, for the information management of biomass supply and logistics. A fundamental part of the information management system is also the Enterprise Resource Planning (ERP) system tailored for energy biomass supply. Read more about the ERP development under **Supply chain design and management (/content/supply-chains/supply-chain-management)**. The input and output data between the biomass ERP and other information management systems used by players in the biomass supply chains were specified. The focus was in advanced biomass measurement systems and what kind of data structures and contents are required from them.

The data model is capable of handling both forest and agricultural biomass, and is designed to be adaptable to other types of biomass. The model covers all the supply chain processes from biomass production to combustion at the power plant. Data hierarchy and structures of papiNet, the global data communication standard of forest industries, were taken as a basis in the design since it is expected to be used in communicating operational data. Introduction of new cloud-based messaging services will further increase the role of papiNet as a de facto communication standard. Applying the papiNet for handling agricultural biomass was also studied and deemed feasible. For equal data access, we investigated means of accessing data and analyzed how different methods of human-machine interaction may affect the data access means a user has and govern the data regarding them.

System integration is an ever more important aspect in boosting efficient cooperation between different actors. A common data model design promotes integration between actors in the digital ecosystem. Similarly, being able to handle also agricultural biomass using the papiNet standard makes building a common ecosystem easier. Providing simple and easy means for all biomass producers to participate in a digital ecosystem is important. The broader ecosystem also means that there are more possible sources of biomass – fuel – available. This allows for

better fuel security for the power plants and makes the ecosystem more robust.

One of the future goals is that all players should have open access to the biomass ERP system and the platform supporting it. The ERP system and applications linked to it can optionally be embedded in companies' IT systems or they can be independent and integrated to other systems via common data interfaces. In the future vision, we see that the operative planning and monitoring of the supply chains will be increasingly based on big data – especially IoT type data – provided by connected devices and sensors. Big data analytics and new data products derived from first phase data sources are potential tools in developing new applications. However, the alternative business models of biomass energy information management platforms still need to be assessed. Different players in the supply chains have different views and needs regarding information. Therefore, we see that the information management will be decentralized but to work properly it must be standardized to a certain degree and rely on commonly agreed concepts, data models and data communication interfaces.

Supply chain design and management

Enterprise Resource Planning (ERP) systems integrate information coming from specific raw material supply operations. Their role is to provide calculations or estimations of energy content, quality attributes and value of the fuels within the supply chain and its operations. The key business planning questions to be answered with this data are often related to fuel storages and how to plan the logistic operations in an optimal way. Current ERP approaches used in energy wood supply are not yet on the level which would enable modern chain-of-custody or exact value based allocation of resources. To leap forward in the efficiency and sustainability of supply chains, the ERP systems are in a key role. In BEST, definitions, data flows and process mapping of ERP systems especially for the precise control and management of energy biomass supply were described.

One focus area in BEST was studying the drying of the raw material and dry matter losses occurring during storing, which have a large effect on how the supply chain should be designed. Based on these studies, moisture content forecasting functions were created, which can be used as a part of the ERP system or other planning applications (see **Quality measurements and forecasting (/content/supply-chains/quality-measurements-and-forecasting)** for more information). Typically, energy wood is stored for relatively long times at the roadside to decrease the moisture content and to balance the discrepancies between supply and demand. Costs and losses caused by natural biological processes, like decaying and decomposing, have not been studied carefully before and, especially, they have not been monitored in a wider context. In BEST, dry matter losses and capital costs during different storage periods were studied and their remarkable economic effects were identified. These findings motivated to create the Fast Track approach, where the easily decaying material is supplied directly without storing. The timing of the supply operations is carefully planned, storage times are avoided during summer and autumn, and a remarkable part of the feedstock is used as "green", if boilers can tolerate it. The fast track leads to clear economic benefits – 8-13% lower costs due to decreased dry matter losses and smaller capital costs.

Another alternative operation model to the terminal-based supply chains is so-called precision supply, where the roadside storages are allocated based on moisture content, size and transportation distance, and the best storages are utilized at the time of the demand peaks. This way the same plant can produce up to 20-30% more energy during peak demand in the wintertime.

Quality and characteristics of the fuel and feedstock affect the efficiency of the boiler and may significantly influence its performance. However, real-time fuel quality information is often not available in time for optimizing the boiler performance, and the feedback from the boiler performance does not reach the supply chain. In BEST, the relationship between the feedstock quality and boiler performance were studied in several trials. Information systems were analysed as well, and solutions created for using the end user's data to take the fuel quality control of the whole supply chain to the next level. The results and recommendations can be summarised as follows: The boiler information needs to be known in right form at the feeding, the quality of every truck load or railway container must be known, different raw material qualities must be kept separated in the mill-yard storages and the manoeuvres must be planned and proactive. The fundamental precondition for connecting boiler information and feedstock control is the information system and the quality of the data in it.

Stumps from clearcuttings are a significant but contradictory source of renewable energy. The quality of wood for energy in stumps is very good and the harvesting happens on clear cutting sites simultaneously with other harvesting activities. The challenges in the stump wood supply chain are in lifting technology, soil contamination of the stumps and in the transportation efficiency. BEST made remarkable efforts to improve the whole stump supply chain. First trials focused on post-lifting technology, compression at the roadside and screening at terminals. Compression proved much too inefficient and screening quite expensive, even if quality enhancement was remarkable. Solving both cost and quality problems requires new solutions for stump lifting. The studied new excavator-based device separates stump wood and root collars from roots in one or two pieces. It proved to be an efficient option both from quality and productivity point of view. Other clear benefits were very low ground disturbance level, purity and 30% bigger payload compared to stumps lifted traditional way.

All improvements described above and in the other supply chain subtopics can be managed by the modern ERP for energy biomass. It also enables value based management of the material flows and tracing the origin of the material and ensures that measurements are accurate and done in the optimal phase of the supply.

Publication - Conference paper

PUBLICATION TITLE	PUBLISHER	AUTHOR(S)	DATE
Advanced Solutions for Biomass Transportation by Road - How to Evaluate their Performance	24th European Biomass Conference and Exhibition, Amsterdam, the Netherlands, 6.-9.6.2016	Korpinen, O-J., Venäläinen, P., Aalto, M., Ranta, T.	9.6.2016
Analysis of future city energy systems based on official strategies and policies_the role of bioenergy	Venice 5th Symposium on energy from biomass and waste, Venice, Italy, 17.-20.11.2014	N.Miettinen, T. Kurka, M.Särkilahti, J.Rahkonen, J.Rintala	17.11.2014
Comparison of high density laser scanning methods for tree-level biomass estimation	22nd European Biomass Conference and Exhibition, Hamburg, Germany, 23.-25.6.2014	Ville Kankare, Markus Holopainen at al.	23.6.2014
Creating Moisture Prediction Models For Seasoned Fuelwood	International Bioenergy (Shanghai) Exhibition and Asian Bioenergy Conference 2015 (IBSCE). 21-23 October, 2015, Shanghai.	J. Raitila, V-P. Heiskanen, M. Kolström, J. Routa	23.10.2015
Exploiting the unexploited biomass energy in India through Finnish CHP solutions	The International Conference on Informatics, Environment, Energy and Applications (IEEA 2015), Pattaya, Thailand, 28.-29.3. 2015	Karthikeyan Natarajan, Paavo Pelkonen	28.3.2015
Forest Fuel Supply Through the Terminal Network in Finland and Sweden	24th European Biomass Conference and Exhibition, Amsterdam, the Netherlands, 6.-9.6.2016	Matti Virkkunen, Jyrki Raitila	9.6.2016
Fuel wood drying modelling - the European experience	CROJFE 2015, 18th - 20th March 2015, Zagreb	Gernot Erber, Johanna Routa, Lauri Sikanen, Lars Wilhelmsson, Jyrki Raitila	20.3.2015
Geographical distribution of techno-economic harvest potential of straw for energy use and biorefining in Finland	Bioenergy 2015 - International bioenergy exhibition and conference 2.-4.9.2015, Jyväskylä, Finland. Proceedings, p. 35-40	O.-J. Korpinen, T. Ranta, T. Lötjönen, E. Lehtonen	4.9.2015
GHG impact dynamics of bioenergy from boreal forests	Bioenergy Australia 2013 Conference, Abstract book (p. 48)	Sampo Soimakallio, VTT	25.11.2013
GIS-based location analysis of a large forest-fuel feeder terminal in greater Helsinki area	World Bioenergy Conference, Jönköping, Sweden 3-5 June 2014	Olli-Jussi Korpinen, Eero Jäppinen, Perttu Anttila, Tapio Ranta	3.5.2014
Health Issues in the Bioenergy Supply Chain - Aims at best practices	Bioenergy 2015 - International bioenergy exhibition and conference 2.-4.9.2015, Jyväskylä, Finland. Proceedings, p. 63-68	Kirsi Korpijärvi, Leena Fagernäs et al.	4.9.2015
Horizon scanning for social sustainability in the bioenergy value chain	7th International Scientific Conference, Energy and Climate Change, Green Economy 8-10 October, 2014 Athens Greece	Elena Fedorova, Eva Pongrácz	8.10.2014
Impacts of climate policies and energy technology paths on the global wood demand and supply	IBFRA Conference proceedings. May 24–29, 2015, Rovaniemi, Finland, p. 25	Maarit Kallio, Birger Solberg, Antti Lehtilä, Tiina Koljonen, Alexander Moiseyev	29.5.2015
Large scale biofuel supply possibilities to Helsinki – feedstock availability and logistics	Book of Proceedings, Bioenergy from Forest 2014, 16. - 17.9.2014, p. 82	E. Jäppinen, O.-J. Korpinen, J. Rauhamäki, T. Ranta	17.9.2014
Multi-criteria assessment for evaluation of social sustainability of bioenergy	10th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Sep 27 - Oct 3, 2015, Dubrovnik, Croatia	Elena Fedorova, Eva Pongrácz	3.10.2015
Operation economy of CHP plants using forest biomass and peat	24th European Biomass Conference & Exhibition (EUBCE), Amsterda, The Netherlands, 6-9 June 2016	M. Hurskainen, J. Kärki & J. Raitila	9.6.2016
Opportunities of bioenergy-based CHP production in balancing renewable power production	European Energy Market Conference (EEM), Porto, Portugal, 6-9 June 2016	Juha Haakana, Ville Tikka, Jukka Lassila, Jarmo Partanen	6.6.2016
Optimal location for a large forest-fuel terminal near Helsinki metropolitan area	22nd European Biomass Conference and Exhibition, Hamburg, Germany, 23.-26.6. 2014	Olli-Jussi Korpinen, Eero Jäppinen, Perttu Anttila, Tapio Ranta	23.6.2014

PUBLICATION TITLE	PUBLISHER	AUTHOR(S)	DATE
Planning the sustainable use of agricultural bioresources as fuel for city busses: example case Turku, Finland	In Proceedings of RAMIRAN 2015 16th International Conference Rural-Urban Symbiosis 8th-10th September 2015	Saija Rasi	9.9.2015
Precision measurement of forest biomass moisture change and dry matter losses by constant weight monitoring	Proceedings of the Nordic Baltic Conference OSCAR14 - Solutions for Sustainable Forestry Operations (p. 60) June 25-27, Knivsta, Sweden	Johanna Routa, Lauri Sikanen, Marja Kolström	27.6.2014
Predicting moisture and economic value of solid forest fuel piles for improving the profitability of bioenergy use	EGU General Assembly 2016, Vienna, Austria, 17–22 April 2016	Ari Lauren, Jyrki-Pekko Kinnunen, and Lauri Sikanen	22.4.2016
Prospects for biomass use in large power plants in the EU-27 and the role of Combined Heat and Power production	European Energy Market conference, Krakow, 28.-30.5.2014	Mikko Wahlroos, Sam Cross, Sanna Syri	28.5.2014
Reconsideration of the land use baseline may have a significant impact on the ghg balances of agro-bioenergy	Bioenergy Australia 2013 Conference, Abstract book (p. 47)	Kati Koponen, VTT	25.11.2013
Resource recovery via distributed biogas production		Saija Rasi, Elina Tampio, Viljami Kinnunen, Jukka Rintala	22.11.2016
Risks to workers' safety and health in biomass processing	International Congress and Expo on Biofuels & Bioenergy, August 25-27, 2015, Valencia, Spain	Sirpa Laitinen, Juha Laitinen et al.	27.8.2015
Simulation Approach to Estimate Logistic at Three Different Biomass Terminal Classes	24th European Biomass Conference and Exhibition, Amsterdam, the Netherlands, 6.-9.6.2016	Aalto, M., Korpinen, O-J., Ranta, T.	9.6.2016
Simulation Modelling in Biomass Logistics - Benefits, Challenges and Three Case Studies	23rd European Biomass Conference & Exhibition (EUBCE), 1-5 June 2015, will be published in August 2015	Eero Jäppinen, Olli-Jussi Korpinen, Raghu KC, Tapio Ranta	1.6.2015
Systematic approach to holistic identification of local sustainability questions in bioenergy production chains - Case biobutanol from Brazil to the EU	10th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Sep 27 - Oct 2, 2015, Dubrovnik, Croatia	Heli Rimppi, Ville Uusitalo, Sanni Väisänen, Risto Soukka, Jouni Havukainen	27.9.2015
Terminal cost analysis for forest fuel supply in Finland	International Bioenergy (Shanghai) Exhibition and Asian Bioenergy Conference 2015 (IBSCE). 21-23 October, 2015, Shanghai.	Matti Virkkunen & Jyrki Raitila	23.11.2015
Terminal Cost Analysis for Forest Fuel Supply in Finland	International Bioenergy (Shanghai) Exhibition and Asian Bioenergy Conference 2015 (IBSCE). 21-23 October, 2015, Shanghai.	Matti Virkkunen, Jyrki Raitila	23.10.2015
The Accuracy of National ALS Data in Biomass Mapping in Finland	22nd European Biomass Conference and Exhibition, Hamburg, Germany, 23-25 June 2014.	Ville Kankare, Jari Vauhkonen et al.	23.6.2014
The importance of dry matter loss and capital costs in energy wood supply chain	Proceedings of the Nordic Baltic Conference OSCAR14 - Solutions for Sustainable Forestry Operations (p. 51) June 25-27, Knivsta, Sweden	Lauri Sikanen, Marja Kolström, Johanna Routa	27.6.2014
Workers' exposure to biological and chemical agents in biomass processing at CHP plants	International Congress and Expo on Biofuels & Bioenergy, August 25-27, 2015, Valencia, Spain	Juha Laitinen, Sirpa Laitinen et al.	27.8.2015

Publication - Journal

An assessment of the uncertainties related to bioenergy applications	Management of Environmental Quality: An International Journal, Vol. 25 Iss: 3, pp.301 - 312	Laura Kainiemi, Sanni Eloneva, Mika Järvinen	1.4.2014
Biomass Resource Assessment and Existing Biomass Use in the Madhya Pradesh, Maharashtra, and Tamil Nadu States of India	Challenges 2015, Vol. 6(1), p. 158-172	Karthikeyan Natarajan, Petri Latva-Käyrä, Anas Zyadin, Suresh Chauhan, Harminder Singh, Ari Pappinen and Paavo Pelkonen	27.5.2015
Coal and biomass co-firing prospects in India	Energetica India, Nov/Dec 2013	Renu Kumar Rathnam, Janne Kärki et al.	1.11.2013

PUBLICATION TITLE	PUBLISHER	AUTHOR(S)	DATE
Cost analysis of a satellite terminal for forest fuel supply in Finland	Scandinavian Journal of Forest Research, Vol. 31 (2016), p. 175-182	Jyrki Raitila, Matti Virkkunen, Olli-Jussi Korpinen	14.8.2015
Discrete event simulation of an information-based raw material allocation process for increasing the efficiency of a energy wood supply chain	Applied Energy, vol. 149 (2015), p. 315–325	Johannes Windisch, Kari Väätäinen et el.	1.7.2015
Environmental sustainability and improvement options for agribiomass chains: Straw and turnip rape	Biomass and Bioenergy, Volume 83 (2015) p.1–7	Katri Joensuu, Taija Sinkko	7.8.2015
Exploiting the Unexploited Biomass Energy in India through Finnish CHP Solutions	4th International Conference on Informatics, Environment, Energy and Applications, Volume 82 of IPCBEE (2015)	Karthikeyan Natarajan, Paavo Pelkonen	30.4.2015
Exposure to biological and chemical agents at biomass power plants	Biomass and Bioenergy Vol. 93, October 2016, p. 78–86	S. Laitinen, J. Laitinen et al.	6.7.2016
Farmers' willingness to supply biomass for energy generation: evidence from South and Central Poland	Biofuels	A. Zyadin, K. Natarajan et al.	14.9.2016
Field trial results of straw yield with different harvesting methods and modelled effects on soil organic carbon	Biomass and Bioenergy (2016), Vol. 95, p. 8–18	Kaija Hakala, Jaakko Heikkinen, Taija Sinkko, Katri Pahkala	1.12.2016
Forest Biomass for Energy Production: Perceptions of State Forestry Professionals from China and India	Challenges 2014, Vol. 5(2), p. 338-350	Pradipta Halder	16.10.2014
Forest inventory attribute prediction using airborne laser scanning in low-productive forestry-drained boreal peatlands	Silva Fennica (2015) vol. 49 no. 2	Mikko Niemi, Mikko Vastaranta, Jussi Peuhkurinen, Markus Holopainen	20.3.2015
Indian Farmers' Perceptions and Willingness to Supply Surplus Biomass to an Envisioned Biomass-Based Power Plant	Challenges 2015, Vol. 6(1), p. 42-54	Anas Zyadin, Karthikeyan Natarajan, Suresh Chauhan, Harminder Singh, Md. Kamrul Hassan, Ari Pappinen and Paavo Pelkonen	27.5.2015
Logistical, economic, environmental and regulatory conditions for future wood pellet transportation by sea to Europe: The case of Northwest Russian seaports	Renewable and Sustainable Energy Reviews 56 (2016) 38-50	Svetlana Proskurina, Heli Rimppi et al.	28.1.2016
New methodological approach for biomass resource assessment in India using GIS application and land use/land cover (LULC) maps	Renewable and Sustainable Energy Reviews, Vol. 63 (2016) pp. 256–268	K. Natarajan, P. Latva-Käyrä, A. Zyadin, P. Pelkonen	1.9.2016
Perspectives of Feedstock Supply for Biomass-Based Energy Plant Development in India - Views from an Expert Survey	Challenges 2015, Vol. 6(1), p. 71-87	Md. Kamrul Hassan, Karthikeyan Natarajan, Paavo Pelkonen, Anas Zyadin and Ari Pappinen	27.5.2015
Precision measurement of forest harvesting residue moisture change and dry matter losses by constant weight monitoring	International Journal of Forest Engineering (2015 Vol. 26, p. 71-83	Johanna Routa, Marja Kolström, Johanna Ruotsalainen & Lauri Sikanen	16.3.2015
Puustobiomassan kartoituksen ja seurannan kehittäminen	Metsätieteen aikakauskirja 01/2015	Ville Kankare, Mikko Niemi, Mikko Vastaranta, Markus Holopainen, Juha Hyyppä	13.5.2015
Retrieval of Forest Aboveground Biomass and Stem Volume with Airborne Scanning LiDAR	Remote Sensing 2013, 5(5), p. 2257-2274	Kankare, V., Vastaranta, M. et al.	13.5.2013
Single tree biomass modelling using airborne laser scanning	ISPRS Journal of Photogrammetry and Remote Sensing Vol. 85, Nov 2013, Pages 66–73	Kankare, V. et al.	14.9.2013
Sparse density, lea-off airborne laser scanning data in aboveground biomass component prediction	Forests (2015), 6, p. 1839-1857	Ville Kankare, Jari Vauhkonen et al.	28.5.2015

PUBLICATION TITLE	PUBLISHER	AUTHOR(S)	DATE
Sustainability criteria of bioenergy systems from steering, research and Finnish bioenergy business operators' perspectives	Ecological Indicators 66 (2016) 357-368	Heli Rimppi, Ville Uusitalo, Sanni Väisänen, Risto Soukka	18.2.2016
TerraSAR-X Stereo Radargrammetry and Airborne Scanning LiDAR Height Metrics in Imputation of Forest Aboveground Biomass and Stem Volume	IEEE Transactions on Geoscience and Remote Sensing 2014a, 52 (2), 1197-1204	Mikko Vastaranta, Markus Holopainen et al.	28.3.2013
Validation of prediction models for estimating the moisture content of logging residues during storage	Biomass and Bioenergy	Johanna Routa	21.11.2016
Validation of prediction models for estimating the moisture content of small diameter stem wood	Croatian Journal of Forest Engineering vol. 36 no 2 (2015) pp. 283-291	Johanna Routa, Marja Kolström, Johanna Ruotsalainen, Lauri Sikanen	28.9.2015

Publication - Other

	BioEnergia-lehti	Sami Siikanen, Lauri Sikanen, Jukka Antikainen	26.5.2016
	BioEnergia-lehti	Sirpa Laitinen	29.10.2015
BEST-ohjelma vahvistaa asemaamme energia-areenoilla	BioEnergia-lehti	Kaisu Leppänen	7.11.2013
Bioenergian laadun ja määrän hallinta	Bioenergia-lehti	Timo Melkas	30.4.2015
Terminaalit tuovat tehokkuutta bioenergian raaka-ainetoimituksiin	Bioenergiamittari -lehti s.8 (julkaistu myös Lähienergia-lehdessä)	Jouni Tornberg	16.6.2014
Volyymillä tehoa terminaaleihin	ForestEnergy 2020 newsletter	Matti Virkkunen	8.10.2014
Volyymillä tehoa terminaaleihin	Koneyrittäjä	Matti Virkkunen	1.9.2014

Publication - Poster

	BEST final seminar	Jyrki Raitila, Matti Virkkunen	29.11.2016
Biomass Pyrolysis and Combustion – From Experimental Measurements to Numerical Modelling	BEST final seminar	Niko Niemelä, Henrik Tolvanen, Teemu Saarinen, Aino Leppänen, Antti Oksanen	29.11.2016
Biomass Resource Assessment in Poland	BEST final seminar	Petri Latva-Käyrä, Karthikeyan Natarajan, Anas Zyadin	29.11.2016
Biomass terminal as concept for adding value to bioenergy	SHOK Summit 2014, Helsinki, poster session	Matti Virkkunen, Jyrki Raitila	14.5.2014
Case studies of biomass use in power and CHP plants in India	BEST final seminar	Janne Kärki, Arvo Leinonen, Markus Hurskainen	29.11.2016
Combustibility of Empty Fruit Bunch (EFB) Pellets in Circulating Fluidized Bed Combustion	BEST final seminar	Cyril Bajamundi, Timo Leino, Martti Aho, Jouni Hämälainen, Merja Hedman, Juha Roppo	29.11.2016
Data Model for Information Management of Bioenergy Supply Chains	BEST final seminar	Tapio Räsänen, Kirsi Riekki, Juha-Antti Sorsa, Jussi Nikander, Markku Koistinen	29.11.2016
Harvest and storage of moist cereal straw - poster	BEST final seminar	Timo Lötjönen, Vesa Joutsjoki	29.11.2016
Hyvä työturvallisuus tavaksi biolaitoksilla	BEST final seminar	Sirpa Laitinen, Kirsi Korpijärvi et al.	29.11.2016
Improving the Biomass Supply Chain Through ICT Solutions	BEST final seminar	Anas Zyadin, Karthikeyan Natarajan	29.11.2016

PUBLICATION TITLE	PUBLISHER	AUTHOR(S)	DATE
India - Case study for bioenergy applications	SHOK Summit 2014, Helsinki, poster session	Pradipta Halder	14.5.2014
Measurements in a forest-based material supply chain	BEST final seminar	Timo Melkas, Jouni Tornberg, Henna Karlsson	29.11.2016
OPERATION ECONOMY OF CHP PLANTS USING FOREST BIOMASS AND PEAT	EUBCE conference 2016, Amsterdam	Markus Hurskainen, Janne Kärki & Jyrki Raitila	9.6.2016
Rural biomasses in urban cycles	BEST final seminar	Elina Tampio, Saija Rasi et al.	29.11.2016
The possible roles of different parts of the power and heat production chain in a sustainable system	BEST final seminar	Samuli Rinne	29.11.2016
Valorization of non-wood biomass - case studies with food industry side streams and municipal food waste	BEST final seminar	Saija Rasi, Minna Kahala et el.	29.11.2016

Publication - Presentation

(How) Can centralised waste and sanitation infrastructure be replaced with local biogas treatment and nutrient recycling? Case Tampere	BEST final seminar	Maarit Särkilahti	29.11.2016
BEST presentation at FIBIC seminar	FIBIC seminar in Hanasaari 20.11.2013	Kaisu Leppänen	20.11.2013
Bioenergia ilmastosopimuksen jälkeen - vakaa kasvu vai luova tuho?	BEST final seminar	Antti Asikainen	29.11.2016
Bioenergiaskenaariot 2033 - mitä skenaariota äänestäisit nyt?	BEST final seminar	Jyrki Kettunen	29.11.2016
Bioenergy conflicts and their management - A global review	Energy & Society conference, Krakow 4.-6.6.2014	Marika Makkonen, Suvi Huttunen, Mikael Hildén	6.6.2014
Bioenergy resources (CHP) providing energy system flexibility	BEST final seminar	Juha Haakana	29.11.2016
Business opportunities and challenges in new markets	BEST final seminar	Karthikeyan Natarajan	29.11.2016
Dynamic simulation tools for the evaluation of biomass supply systems	BEST final seminar	Olli-Jussi Korpinen	29.11.2016
Effective biomass handling - predicting models and fast track supply	BEST final seminar	Johanna Routa	29.11.2016
Implications of the upcoming EU energy policy package for the bioenergy sector	BEST final seminar	Sam Cross	29.11.2016
Kiinteiden biopolttoaineiden terminaaliratkaisut tulevaisuudessa	ForestEnergy 2020 -vuosiseminaari	Matti Virkkunen	8.10.2014
Ministeriön tervehdys	BEST final seminar	Riku Huttunen	29.11.2016
Miten rakennetaan kestävää liiketoimintaa 1	BEST final seminar	Risto Soukka	29.11.2016
Miten rakennetaan kestävää liiketoimintaa 2	BEST final seminar	Sari Kuusisto	29.11.2016
Riittääkö metsähaketta lämpö- ja voimalaitoksille	Uusiutuvan energian ajankohtaispäivät 2016	Perttu Anttila	26.1.2016
Tehokkaan logistiikan ja toimitusketjujen merkitys	BEST final seminar	Timo Saarentaus	29.11.2016
Terminaalit - tehoa energiapuun hankintaan	Bioenergiasta voimaa aluetalouteen -seminaari 28.10.2014, Kajaani	Jyrki Raitila	28.10.2014

PUBLICATION TITLE	PUBLISHER	AUTHOR(S)	DATE
Tulevaisuuden kestävät bioenergiaratkaisut (BEST) -ohjelman anti	BEST final seminar	Kaisu Leppänen	29.11.2016
Tulevaisuuskuvat elinvoimaisista bioenergiakonsepteista	BEST final seminar	Risto Sormunen	29.11.2016

Publication - Report

A prediction model prototype for estimating optimal storage duration and sorting	Working Papers of the Finnish Forest Research Institute	Gernot Erber, Johanna Routa, Lars Wilhelmsson, Jyrki Raitila, Maunu Toiviainen, Juho Riekkinen and Lauri Sikanen	30.6.2014
Agricultural biomass economics and farmers willingness to participate in biomass to energy business in India	BEST program	Anas Zyadin, Karthikeyan Natarajan, Pradipta Halder, Kamrul Hassan, Paavo Pelkonen	12.12.2014
Analysis and development of social sustainability criteria	BEST program	Eva Pongrácz, Elena Fedorova (UOulu)	30.5.2014
Analysis of storing wood residues for energy use	Helen Oy	Juuso Loukola	1.9.2015
Assessing and solving sustainability issues of agribiomass chains: Final results of sustainability assessment	BEST program	Katri Joensuu	31.12.2014
Best scenarios for forest and energy sectors - implications for the biomass market	CLEEN publication series	Maarit Kallio, Antti Lehtilä, Tiina Koljonen, Birger Solberg	23.11.2015
Bigger vehicles to improve forest energy transport	Metsäteho's publication series	Antti Korpilahti	10.2.2015
Bioenergia-autojen optimaalinen kuormakoko ja työmallit irtobiomassojen kuormaamiseen	Metsätehon tuloskalvosarja 3a/2016	Heikki Ovaskainen & Henri Lundberg	15.4.2016
Bioenergy conflicts and their management	CLEEN publication series	Marika Makkonen, Suvi Huttunen, Mikael Hildén	8.9.2014
Biomass resource assessment in the selected states of India - Madhya Pradesh, Maharashtra and Tamil Nadu	BEST program	Petri Latva-Käyrä, karthikeyan Natarajan	19.9.2014
Biomass resources and existing practices in Madhya Pradesh Maharashtra and Tamil Nadu - experiences from field trip	BEST program	Karthikeyan Natarajan, Paavo Pelkonen	21.2.2014
BMA Online biomass moisture analyzers measuring accuracy and feasibility for energy wood materials	Metsätehon tuloskalvosarja 8b/2016	Markku Korhonen, Vesa Fisk, Perttu Laakkonen, Timo Melkas	30.7.2016
Case India - Biomass resource assessment	BEST program	Petri Latva-Käyrä, Karthikeyan Natarajan	13.8.2014
Case Poland: Biomass resouce assessment	BEST program	Petri Latva-Käyrä, Karthikeyan Natarajan, Anas Zyadin	2.3.2016
Case studies on the economic feasibility of biomass use in condensing power and CHP plants in India	BEST program	Janne Kärki	11.3.2015
Case study - Soot sludge drying together with bio-based material	BEST program	Jari Hiltunen	27.10.2015
Combustibility of EFBs in Circulating Fluidized Bed	CLIC Innovation	Bajamundi C, Leino T, Aho M, Hämälainen J, Hedman M & Roppo J.	1.4.2016

PUBLICATION TITLE	PUBLISHER	AUTHOR(S)	DATE
Communicating social sustainability	BEST program	Elena Fedorova and Eva Pongrácz	31.12.2015
Comparing moisture content results of chips and sawdust determined with Metso MR Moisture analyzer and oven drying	Metso Automation, University of Oulu, Metsä Group, Stora Enso	Kalle Kemppainen, Ari Ämmälä	13.12.2013
Compression potential in energywood load	Metsäteho's publication series	Asko Poikela, Metsäteho	10.2.2015
Conceptual design of BIGCC	BEST program	Jari Hiltunen	29.9.2014
Consumer views and their effects on bioenergy futures in different countries	BEST program	Arho Toikka	30.12.2014
Current biomass supply and utilisation chains for energy in India	BEST program	Arvo Leinonen	28.1.2015
Development of Bioenergy Policies in India within the Framework for National Energy Policies and Strategies	BEST program	Pradipta Halder	
Development of simulation tools for terminal-based biomass feedstock logistics	BEST program	Olli-Jussi Korpinen, Eero Jäppinen, Tapio Ranta	16.6.2015
Development status of fast pyrolysis	BEST program	Jari Hiltunen	29.12.2016
Difficulties in the sustainability assessment of agribiomass chains	BEST program	Katri Joensuu	27.8.2014
Elucidation of the potential of high yielding energy crops	MTT	Antti Laine	18.12.2014
Energy Biomass Supply Chain Concepts Including Terminals WP3 Final Report	BEST WP3 Final Report	Lauri Sikanen, Olli-Jussi Korpinen, Jouni Tornberg, Timo Saarentaus, Kaisu Leppänen & Miina Jahkonen (eds.)	29.11.2016
EU-level Scenarios for primary biomass demand to 2020 and 2030	CLEEN publication series	Sam Cross, Mikko Wahlroos, Sanna Syri	30.1.2015
European forest industry and forest bioenergy outlook up to 2050: A synthesis	CLEEN publication series	Hänninen, Hetemäki, Hurmekoski, Mutanen, Näyhä, Forsström, Viitanen & Koljonen	10.6.2014
Expansion of biomass capacity in central Europe		Mikko Wahlroos, Sam Cross, Sanna Syri (Aalto)	11.2.2014
Finnish-Indian partnerships for strengthening research cooperation and developing research methodology (NETWORKING)	BEST program	Paavo Pelkonen, Karthikeyan Natarajan, Pradipta Halder	26.12.2014
Forest Biomass Water Footprint	BEST program	Kimmo Lahti-Nuuttila	19.12.2014
Forest products market outlook - in Future of the European forest-based sector	EFI, What science can tell us 6, 2014	Lauri Hetemäki, Elias Hurmekoski	15.12.2014
GHG impacts related to forest bioenergy: Case Joutseno		Tuomas Helin, Kim Pingoud, Sampo Soimakallio VTT, Jari Hynynen, Hannu Salminen, Saija Huuskonen METLA Jari Liski, Anna Repo SYKE	27.7.2016
Harvest and storage of moist cereal straw	Luke	Lötjönen, T. & Joutsjoki, V.	27.2.2015
Health issues in bioenergy production and use	BEST program	Fagernäs, Ojanen, Jokiniemi, Korpinen (eds)	15.4.2014
Information management of bioenergy supply chains	Metsäteho report	Tapio Räsänen, Juha-Antti Sorsa, Metsäteho	8.1.2015

PUBLICATION TITLE	PUBLISHER	AUTHOR(S)	DATE
Integration of biomass torrefaction with a CHP plant Final Report	Fortum, Andritz, LUT	Sermyagina E, Saari J & al (LUT)	6.3.2014
Integration of torrefied biomass production plant with CHP plant	Fortum, Andritz	Fortum, Andritz	20.3.2014
Kestävää bioenergian tuotantoa Suomessa ja Intiassa - mistä tekijöistä kestävyys muodostuu	BEST program	Kaija Hakala, Katri Joensuu	6.5.2015
Kokopuun paalauksen kilpailukyky	Metsätehon raportti 225	Tuomas Ala-Varvi, Heikki Ovaskainen / Metsäteho	28.10.2013
Kokopuun paalauksen kilpailukyky_tuloskalvosarja	Metsätehon tuloskalvosarja 8/2013	Tuomas Ala-Varvi, Heikki Ovaskainen	28.10.2013
Langattomat lämpötila- ja kosteusanturit metsähakkeen laadun seurannassa	Metsätehon tuloskalvosarja 6a/2016	Jouni Tornberg, Timo Melkas	1.7.2016
LCA analysis of novel high-yielding bioenergy crops compared with willow and reed canary grass	MTT	Antti Laine, Timo Lötjönen, Kirsi Usva, Heli Yrjänäinen	18.12.2014
Measurements at the bioterminal based on MWh-roadmap	Metsäteho's publication series	Timo Melkas, Metsäteho, Jouni Tornberg, Measurepolis Development	16.2.2015
Methane production from anaerobic co-digestion of municipal solid waste and sewage sludge	Tampere University of Technology, report based on a Master's thesis.	EHSAN FATHI AGHDAM, Marja Palmroth, Maarit Särkilahti, Jukka Rintala	15.12.2014
Metsäbiomassan kartoitus ja seuranta yksityiskohtaisella kaukokartoituksella	BEST program	Markus Holopainen, Juha Hyyppä	31.12.2015
Multi-level sociopolitical institutional support systems for decentralized small-scale bioenergy systems in Finland	BEST program	Arho Toikka	14.4.2016
MWh roadmap (in English)	Metsäteho's publication series	Timo Melkas, Metsäteho, Jouni Tornberg, Measurepolis Development	16.2.2015
MWh roadmap (suomeksi)	Metsätehon tuloskalvosarja	Timo Melkas, Metsäteho, Jouni Tornberg, Measurepolis Development	16.2.2015
New Residental Area Circular Economy Concept		Kinnunen, Särkilahti, Tampio, Rasi, Kettunen, Rintala	13.1.2017
Non-wood biomass as raw material in biorefinery processes		Saija Rasi, Erika Winquist, Vilja Varho, Minna Kahala, Eila Järvenpää, Yrjö Virtanen, Vesa Joutsjoki, Lucia Blasco	26.1.2017
Occupational hygiene measurements at power plant sites	BEST program	Korpijärvi et al.	4.12.2014
Online X-ray measurement of biofuels	Inray Oy	Janne Kovanen	9.3.2015
Optimal biomass truck load size and work models for loading of loose biomasses	Metsätehon tuloskalvosarja 3b/2016	Heikki Ovaskainen & Henri Lundberg	15.4.2016
Overview of health and safety issues in the logistics of wood and torrefied pellets	BEST program	Fagernäs Leena, Korpijärvi Kirsi, Alakangas Eija	23.11.2016
Polish Farmers' Ability and Willingness to Supply Biomass for Energy Production	BEST program	Anas Zyadin, Karthikeyan Natarajan, Paavo Pelkonen	1.4.2016
Profitability of combined heat and power plants to participate in electrical power reserve markets	BEST program	Juha Haakana	30.11.2015

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Prospects of biomass-based energy project development in India - A synthesis from Indian Forest Service officers survey	BEST program	Kamrul Hassan	30.4.2014
Qualitative and quantitative assessment measures for social sustainability	BEST program	Elena Fedorova, Eva Pongrácz	17.9.2014
Qualitative and quantitative assessment of social sustainability	BEST program	Elena Fedorova and Eva Pongrácz	31.12.2015
Quo Vadis Bioenergia? BEST bioenergiaskenaariot 2033	CLEEN & FIBIC	Jyrki Kettunen, Tarja Meristö	18.11.2014
Quo Vadis Bioenergia? BEST bioenergiaskenaariot 2033 (laajennettu versio)	CLEEN & FIBIC	Jyrki Kettunen, Tarja Meristö	11.12.2014
Reconsideration of the reference situation for agro biomass production	BEST program	Kati Koponen, Sampo Soimakallio, Katri Joensuu, Taija Sinkko	30.6.2014
Renewable Energy Policies and Trends in Biomass Market Development in Poland	BEST program	Paavo Pelkonen, Karthikeyan Natarajan, Anas Zyadin	8.10.2015
Resource efficient future cities –possibilities for food production		Saija Rasi, Elina Tampio, Kari Jokinen, Sanna Marttinen, Sirpa Kurppa, Vilja Varho, Jouni Vielma	26.1.2017
Rural biogas - feasibility and role in the Finnish energy system	BEST program	Sanna Marttinen, Sari Luostarinen, Erika Winquist, Karetta Timonen	23.11.2016
Scenarios of Energy Wood Transport Fleet and Back-haulage	Metsäteho Oy	Pirjo Venäläinen	13.4.2016
Scenarios of Energy Wood Transport Fleet and Back-Haulage	Metsätehon tuloskalvosarja 2b/2016	Pirjo Venäläinen, Asko Poikela	7.4.2016
Senfit online-kosteusanturin soveltuvuus energiaraaka-aineen mittaukseen	Metsätehon tuloskalvosarja 8a/2016	Markku Korhonen, Vesa Fisk, Perttu Laakkonen, Timo Melkas	30.7.2016
Smallholders in product chain: Biofuel producer case study	Neste Oil	Sari Kuusisto, Adrian Suharto, Annamari Enström, Timo Haatainen, Pekka Tuovinen	27.2.2015
Social Risk Screening in Bioenergy Business	Indufor Oy	Indufor Oy	18.9.2014
Social Sustainability Horizon Scanning Components	BEST program	Eva Pongrácz, Elena Fedorova (UOulu)	30.5.2014
Solid biomass fuel terminal concepts and a cost analysis of a satellite terminal concept	VTT Technology	Matti Virkkunen (VTT Oy), Miska Kari (Mantsinen Ltd Oy), Ville Hankalin and Jaakko Nummelin (ÅF Consult Ltd)	12.8.2015
State-of-the-art study of biomass measurement technologies in the bioenergy supply chain	Metsäteho's publication series	Petri Österberg, Jukka Antikainen, Timo Melkas	10.2.2015
State-of-the-art survey of biomass measurements in the biomass supply chain		Petri Österberg, Jukka Antikainen, Timo Melkas	5.5.2014
Synthesis report on bio-based raw material potential and availability	CLEEN publication series	Kaija Hakala, Saija Huuskonen, Timo Lötjönen, Jari Hynynen	21.8.2014
Synthesis report on the available and affordable propagation methods for novel bioenergy crops	CLEEN publication series	Antti Laine	15.6.2015
Synthesis report on utilization of peatland forests for biomass production	CLEEN publication series	Soili Kojola, Pentti Niemistö et al.	22.9.2015

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Tools for companies' competitive position maintenance and sustainability image building	BEST program	Eloneva, Kainiemi, Toikka	5.5.2014
Tulevaisuuden kestävät bioenergiaratkaisut (BEST-loppuraportti)	BEST program		29.11.2016
Uusien peltobioenergiakasvien potentiaali ja käytännön ongelmien edulliset ratkaisut kestävässä energiantuotannossa	CLEEN publication series	Antti Laine	15.6.2015
Vuosaari C Life Cycle Assessment	Helen Oy	Cecilia Salin	22.1.2015
Wireless sensors for moisture and temperature estimation of storages and chip piles	Metsätehon tuloskalvosarja 6b/2016	Jouni Tornberg, Timo Melkas	1.7.2016
Wood pellets in the Baltic countries	Helen Oy	Cecilia Salin	4.7.2014
Work models for multi-tree handling	Metsätehon tuloskalvosarja 8b/2014 / Metsäteho's publication series 8b/2014	Heikki Ovaskainen	14.10.2014

Publication - Thesis

Computational fluid dynamics modeling of pulverized biomass combustion	Tampere University of Technology,	Niko Niemelä	7.10.2015
Hakkuutähdehakekasan rakenteen ja ominaisuuksien muutos varastoinnin aikana	UEF	Ville Maksimainen	21.11.2016
Hakkuutähteen fast track -hankinnan kannattavuus ja mahdollisuudet	Helsingin yliopisto	Jyrki-Pekko Kinnunen	15.5.2016
Hydrogen production processes from biomass	Aalto University	Sanjay Shah	18.12.2014
Kantoenergian laadun parantaminen esimurskauksella ja seulonnalla	Helsingin yliopisto, Maatalous-metsätieteellinen tiedekunta, Metsätieteiden laitos	Juho Salmi	11.12.2014
Kokopuun paalauksen kilpailukyky	University of Helsinki, Department of Forest Sciences	Tuomas Ala-Varvi	13.12.2013
Korjuriin asennettavan kannonnostolaitteen työnajanmenekin, kuljettajan työergonomian ja kantopuun laadun tarkastelu	M Sc thesis, University of Eastern Finland	Joen Sahlman	15.3.2015
Lumen vaikutus peitetyn ja peittämättömän hakkuutähdekasan kosteuteen	UEF	Ville Maksimainen	27.1.2015
Mikrobien aiheuttama kuiva-ainehävikki hakkuutähdekasoissa	UEF	Liisa Kropsu	12.5.2015
Modelling electricity generation and prospects for efficient biomass use in Europe	Aalto University	Mikko Wahlroos	15.12.2014
MUNICIPAL WASTEWATER AND SLUDGE, ENERGY RECOVERY POSSIBILITIES	TUT Bachelor thesis	Samu Vesa	30.11.2014
Peittomateriaalin vaikutus sadeveden pidättyvyyteen energiarankakasassa	UEF	Eetu Myöhänen	28.5.2015
Process redesign in development of forest biomass supply for energy	University of Eastern Finland, School of Forest Sciences, Faculty of Science and Forestry	Johannes Windisch	27.2.2015
Rankahakkeen laadunhallinta aumavarastoinnissa	Lappeenrannan Teknillinen Yliopisto (LUT), Energiatekniikan koulutusohjelma	Juuso Himmanen	4.5.2016

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Selvitys puupellettien käytön ja varastoinnin vaikutuksista työterveyteen ja työturvallisuuteen voimalaitosalueella	Aalto University	Juuso Loukola	1.9.2015
Selvitystyö Saksan ja Puolan pellettien käytöstä	Aalto University	Henri Mäkelä, Helsingin Energia/Aalto	1.10.2013
The role of bioenergy in the energy systems of future cities	Tampere University of Technology	Noora Miettinen	14.9.2014
Työmallit energiapuuautojen kuormaukseen	Helsingin yliopisto, Maatalous-metsätieteellinen tiedekunta, Metsätieteiden laitos	Henri Lundberg	15.2.2016
YHDYSKUNTAJÄTE ENERGIALÄHTEENÄ CHP-LAITOKSESSA	TUT Bachelor thesis	Suvi Suojanen	12.12.2014
Yhdyskuntajätteen sisältämän paperi- ja pahvikuitujakeen hyödyntämispotentiaali	Oulun yliopisto	Jonna Ojala	21.8.2014